NASA Tech Briefs

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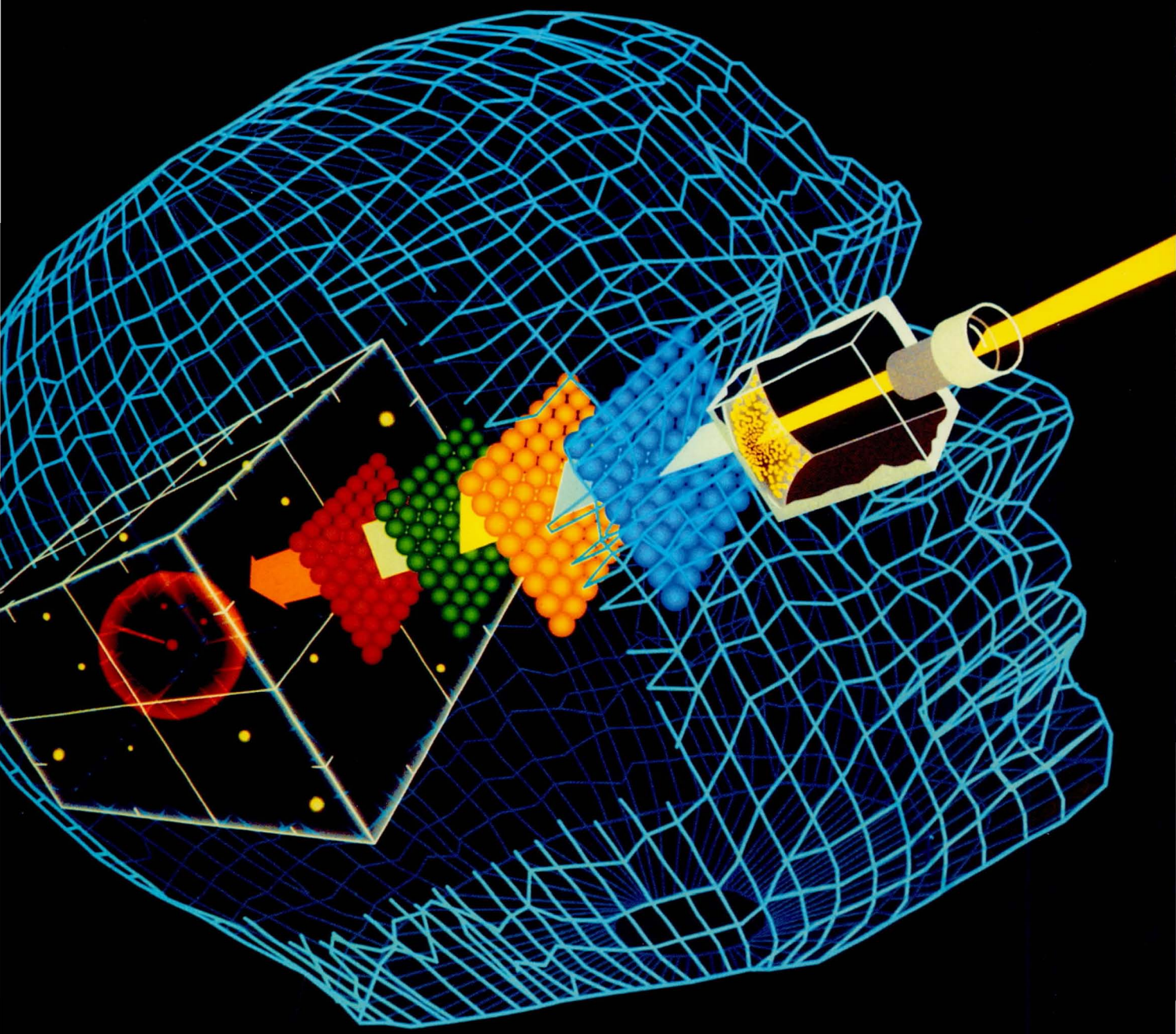
Volume 16 Number 2

Transferring Technology
to Industry and
Government
February 1992



Machine Vision:
Fusing Photonics And AI

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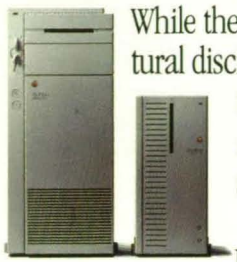


So much power in so little space. The Quadra 900 is just 18.6" high and fits comfortably next to your desk. The Quadra 700 fits comfortably on top of it.

While the engineering and architectural disciplines have always prized the elegant solution, there are times when brute strength is imperative.

Introducing the Apple® Macintosh® Quadra™ 700 and Quadra 900 computers.

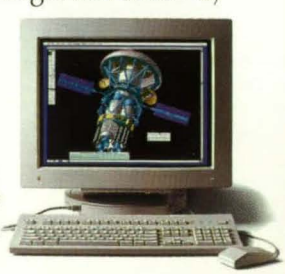
Awesomely powerful. Ferociously fast. But each is still very much a Macintosh.

Up to twice as swift as any of their forebears, they're the first Macintosh computers to be built around the Motorola 68040, rated at 20 MIPS and running at 25 MHz. A highly integrated design, the 040 combines the processor, math coprocessor, memory controller, and cache memory all onto one chip.

More important than merely technical measurements, the Macintosh Quadra computers are totally harmonized systems. The hardware architecture, operating system, interface, peripherals, and networking were all designed from the start to optimize the 040's power and work together smoothly as a single integrated system.

Anyone using compute-intensive applications—like 3-D modeling and stress analysis—will immediately appreciate the difference.

Popular software packages like Infini-D, MicroStation Mac, and Virtus WalkThrough perform more nimbly and



Big just got bigger. The new Macintosh 21" Color Display gives you more drawing board to work on. Colors are vivid, focus is crisp, brightness and contrast are high.

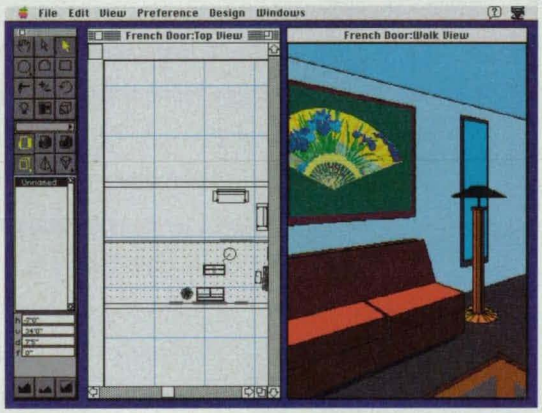
**24-bit video support for up to 16" monitors; 8-bit video support for up to 21" monitors. **There are two easy ways to do it. Simply add an application called SoftPC, or one of two cards from Orange Micro, the Mac286 or Orange386. ©1992 Apple Computer, Inc. Apple, the Apple Camera 1 image was created in Infini-D; Infini-D is a trademark of Specular International, Ltd. Orbiter image was created with MicroStation Mac; MicroStation is a registered trademark of Bentley Systems Inc., an Intergraph affiliate. ORACLE is a registered trademark of and 1-2-3 are registered trademarks of Lotus Development Corporation. SoftPC is a registered trademark of Insignia Solutions Inc. WordPerfect is a registered trademark of WordPerfect Corp. By the way, this ad was designed, typeset, and otherwise created quickly and*

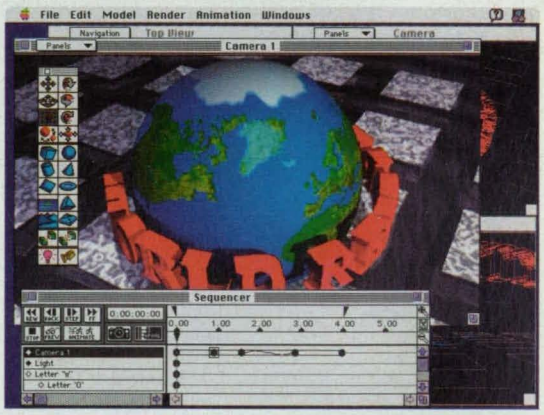
he Mac.

responsively than they ever did before.

And because you do more than design and engineering, these computers also run thousands of Macintosh productivity programs like Lotus 1-2-3 and WordPerfect. Accounting programs like Great Plains. Database programs like ORACLE and FoxBASE+/Mac. And presentation programs like PowerPoint.

mense capacity with five NuBus expansion slots, SuperDrive, plus three additional half-height expansion bays for CD-ROM drives, magneto-optical disk drives, tape backups, or hard disk storage of over 1 gigabyte. And you can add up to 64MB of RAM. It also features a key lock, for security and to protect against interruption of long, compute-intensive jobs.





Because it's a Macintosh, extremely sophisticated programs for interior spatial emulation, 3-D modeling, and CAD/CAM are easy to use. Because it's a Macintosh Quadra, they've got the muscle to run nimbly and quickly. Pictured in action, Virtus WalkThrough and Infini-D.

Both Mac® Quadra models offer a generous array of expansion slots. Which you may never need since so much is already on board. Including high-performance 24-bit color video controllers built onto the logic boards which will run any Apple and many third-party monitors.* Saving both a slot and the cost of a video card. And both come with Ethernet. So you can move large CAD files around the office at warp speed.

The Macintosh Quadra 700 is the same compact size as the popular Macintosh IIci.

It also comes with a SuperDrive™ disk drive, two NuBus™ slots, and a hard drive of up to 400MB. In addition, RAM is expandable up to 20MB.

The Quadra 900 is a standing tower of im-

For all their abilities, Quadra computers are as easy to set up and use as every Macintosh and are capable of running not only thousands of Macintosh applications, but MS-DOS** programs as well.

For the name of your nearest authorized Apple reseller, call 800-538-9696, ext. 320.

For GSA schedule purchases, contact Falcon Microsystems, Inc., in Landover, Maryland (# GS-00K-91AGS-5047), or call 800-825-7989.

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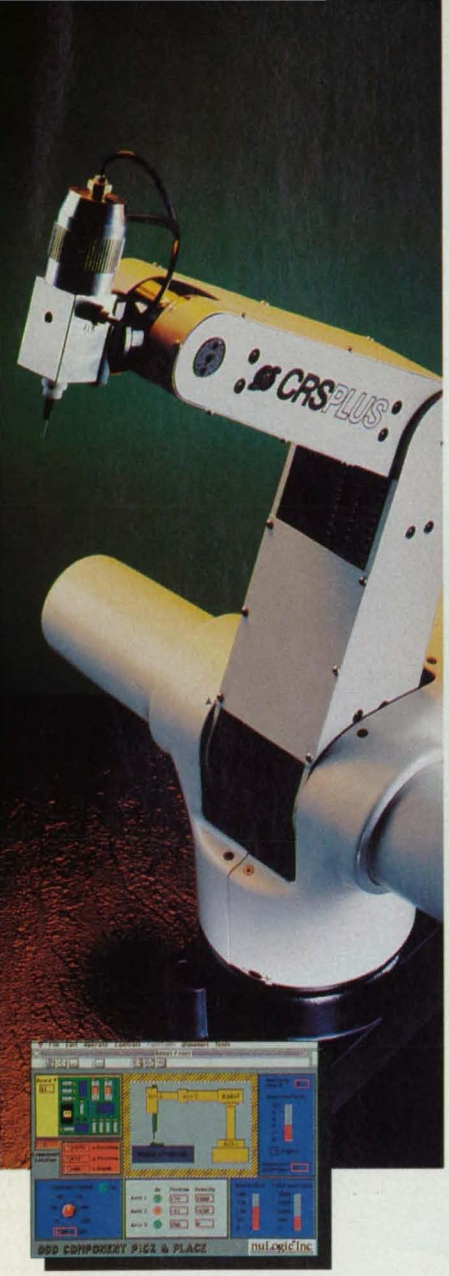

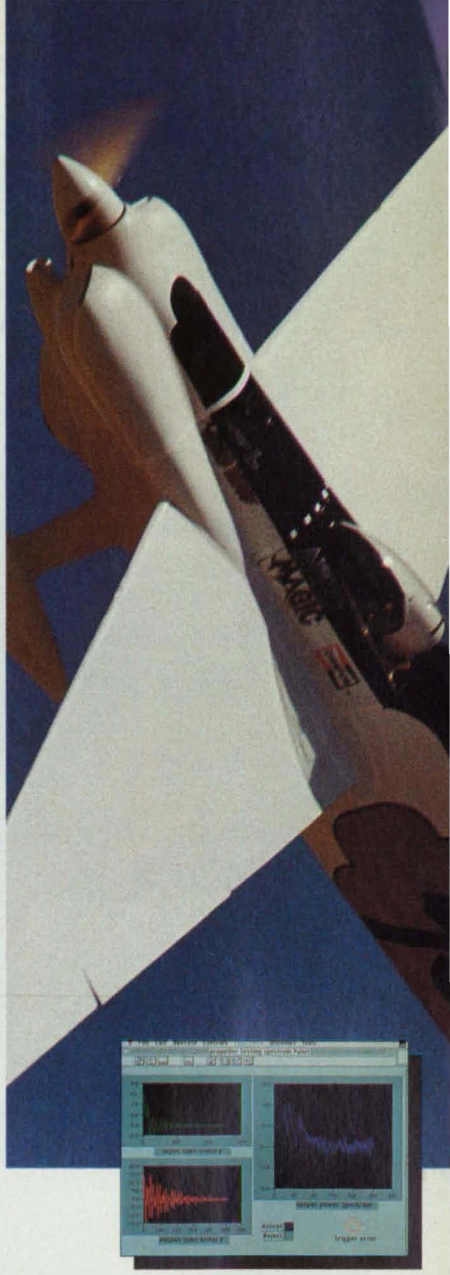

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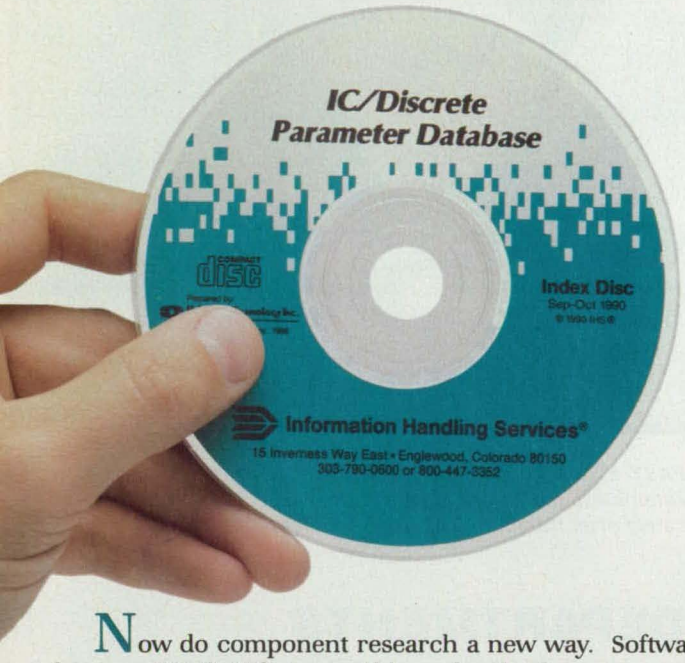

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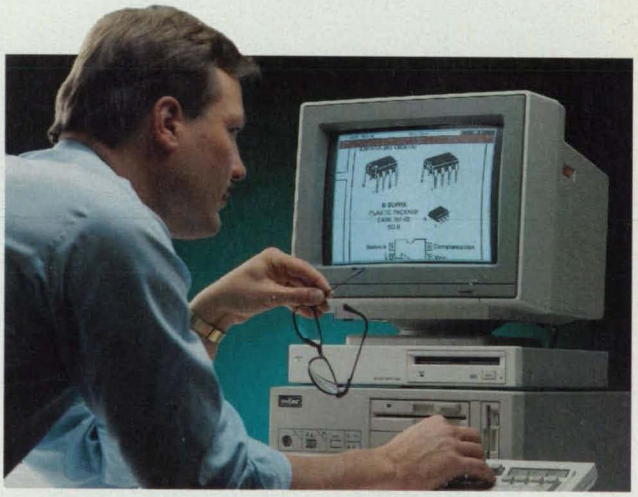

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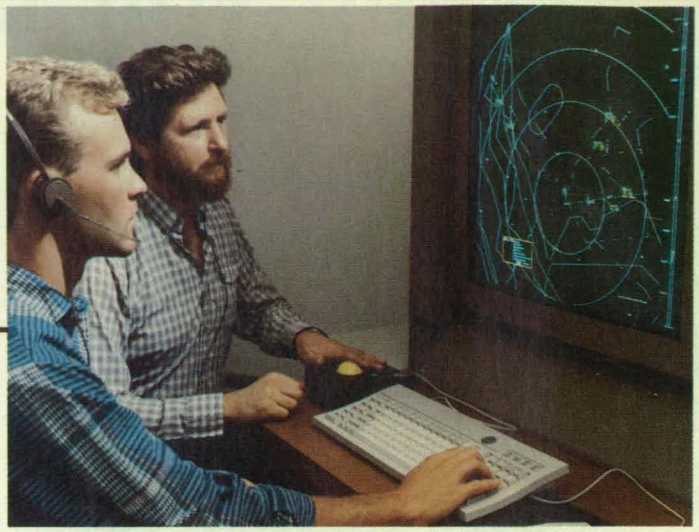

Photo courtesy NASA Ames

FAST, a NASA-developed subsystem of computers, communications equipment, and radar, increases the efficiency and safety of air traffic control. See the tech brief on page 41.

SPECIAL FEATURE

TECHNICAL SECTION

DEPARTMENTS

On The Cover: This computational model of human vision is used by researchers in NASA's Automation Sciences Research Facility to improve machine vision for future remote exploration and robotic applications. When combined with real-time imagery from infrared or millimeter-band radar, such models will enable the creation of synthetic imagery that can help pilots or automated devices to land in low-visibility conditions. Turn to page 10.
(Graphic courtesy Ames Research Center)

Engineers at Ames Research Center have produced an improved flow-through wind tunnel balance (page 70) that is less susceptible to hysteresis and spurious force readings.
Photo courtesy NASA Ames

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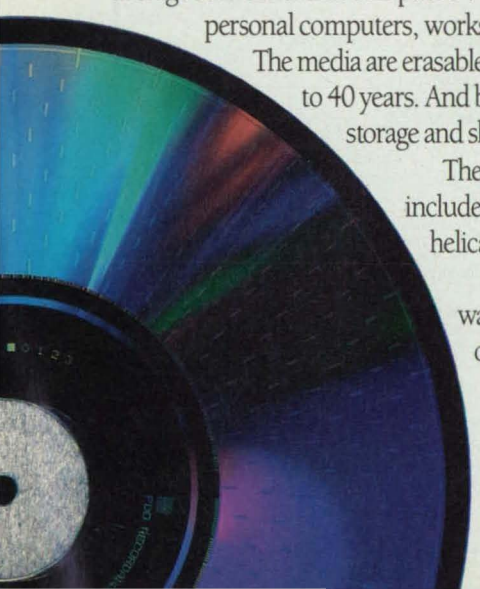

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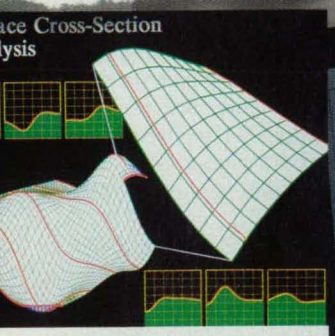

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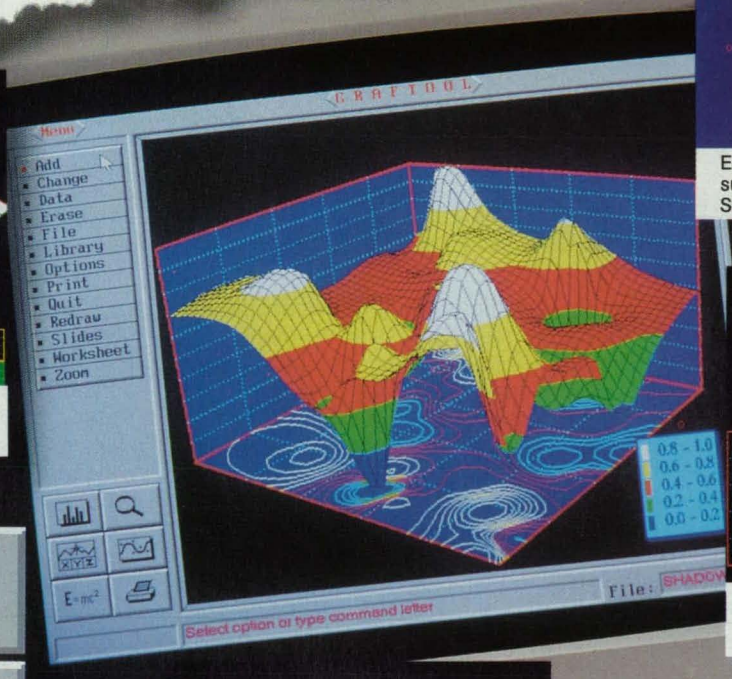

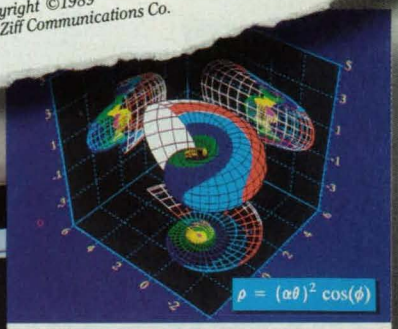

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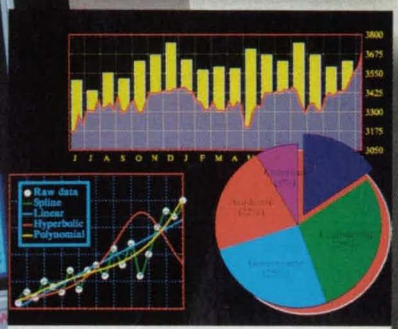

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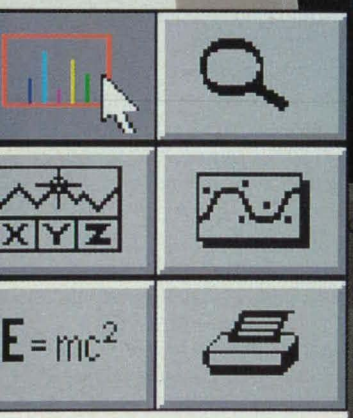

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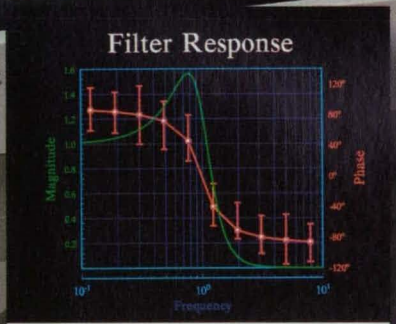

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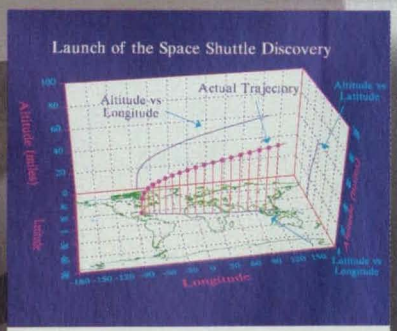

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Photo courtesy of NASA Ames Research Center

Ames' ASRF: Creating Intelligent Machines for Space and Earth

On January 31, NASA dedicated a new research facility that unites under one roof many of the nation's leading experts in artificial intelligence, space data systems, and computational sciences. Located at the Ames Research Center in Moffett Field, CA, the 60,000-square-foot Automation Sciences Research Facility (ASRF) provides a central resource for the development of intelligent systems to support future NASA missions such as the National AeroSpace Plane and the Space Exploration Initiative.

Intelligent, automated machines will enable the construction and operation of space station Freedom, a lunar outpost, and a manned mission to Mars. The machines will allow humans to collect an expanded range of sensory and scientific data on Earth and in space, and will perform extraterrestrial mining and exploration.

"The new facility is good for everything from theoretical work to demonstration," said researcher Ann Patterson-Hine. Its test beds complement NASA's full-scale test beds to facilitate direct transfer to aerospace missions. Scientists can conduct collaborative research in the ASRF's range of laboratories, which include an optical processing lab, advanced computer architectures lab, multiprocessing test bed, and advanced integrated systems test bed.

"The ASRF enables us to live up to our people," said Peter Friedland, a branch chief in Ames' Information Sciences Division, now housed in the ASRF. The division's studies range from multiprocessing to fuzzy control, from photonics to machine learning, converging on the development of machines sophisticated enough to assume tasks that are tedious, impractical, or dangerous for humans. Implanted with vision, touch, and other human senses, robotic devices will perceive and learn from their environment and make decisions based on that knowledge. This will free humans to supervise only higher-level operations, assigning lower-level detailed tasks to the machines.

The Information Sciences Division comprises the Computational Systems Research Branch, the Artificial Intelligence (AI) Branch, and the Spacecraft Data Systems Branch. Computational systems specialists work to advance computer capabilities through parallel processing, photonics, neural networks, and other advanced technologies. AI researchers address data analysis techniques, autonomous control, and knowledge base technology, while those in space data systems focus on data management systems, remote real-time information, and software engineering. The broad range of research areas within the three branches illustrates the large number of advances in software and hardware required to build intelligent machines.

One primary need is for increased computer power, which has turned attention from serial computation on a single machine to parallel processing on multiprocessor architectures. To be effective, however, the software must run well in parallel. Multiprocessing experts in the Computational Systems Research Branch are creating ways to determine a program's performance in parallel and to isolate the causes of performance degradation. They also are investigating computationally-intensive problems such as measuring air flow across an aircraft wing to determine if parallel processing would aid in their solution.

Another research effort looks to overcome the severe constraints space imposes on the weight, volume, and power usage of automated machines. The emerging field of optical processing may provide an answer. Optical processing

An ASRF researcher employs state-of-the-art video compression technology to remotely monitor space experiments.

Photo courtesy of NASA Ames Research Center

is being applied at the ASRF to problems in robotic vision, planetary lander guidance, autonomous aircraft inspection, and optical matrix processing. It can be used to tackle any problem with high data throughput and a repetitive analysis function, such as the analysis of combustion plumes. With optics, according to researcher Max Reid, one can determine the plume composition in real time, possibly in time to shut off the engine if the analysis suggests the casing is burning through.

"Optical processing could be applied to a family of problems where the solution is a matrix and speed is critical," said Reid. "It might one day aid in the improvement of jet engine efficiency."

Optical neural networks are ideal for full interconnections between large collections of objects because light beams can propagate quickly through free space and can pass through each other without interference. "We are working to put the power of a supercomputer for a specific task into something that will fit into the palm of your hand," said Reid. The networks are used for vision processing, one of the most computationally-intensive tasks required of an autonomous robot. A robot must be able to identify images regardless of how they are oriented or how far away they are, even in a cluttered room. Such work may one day spin off new aids for the blind.

ASRF researchers are developing a program for inspecting aging aircraft that employs a magneto-optic eddy current imager to detect internal cracks and corrosion. A research team is using computers to enhance the images and allow the program to analyze a variety of materials. "Our goal is 3D images with depth and quantification, and eventually to automate the system," said team member Deanne Tucker. Another group is developing software to increase the safety and efficiency of flight testing research aircraft, with an eye toward future hypersonic test flights.

Researchers in the ASRF's AI Branch are designing software to imbue complex machines with enough intelligence to complete an assignment such as collecting interesting rocks from the lunar surface, first analyzing how best to complete the job, then executing its plan in a flexible fashion, adjusting for unforeseen circumstances. Such planning, scheduling, and execution by machines will improve as they become more human-like. The addition of machine learning will lead to self-analysis and, with experience, self-improvement.

"Current programs take forever because they consider too many options," said Steve Minton, who designed a scheduler for the Hubble Space Telescope. "By putting in some common sense, we cut down the number of trials. The system knows what a human would try first."

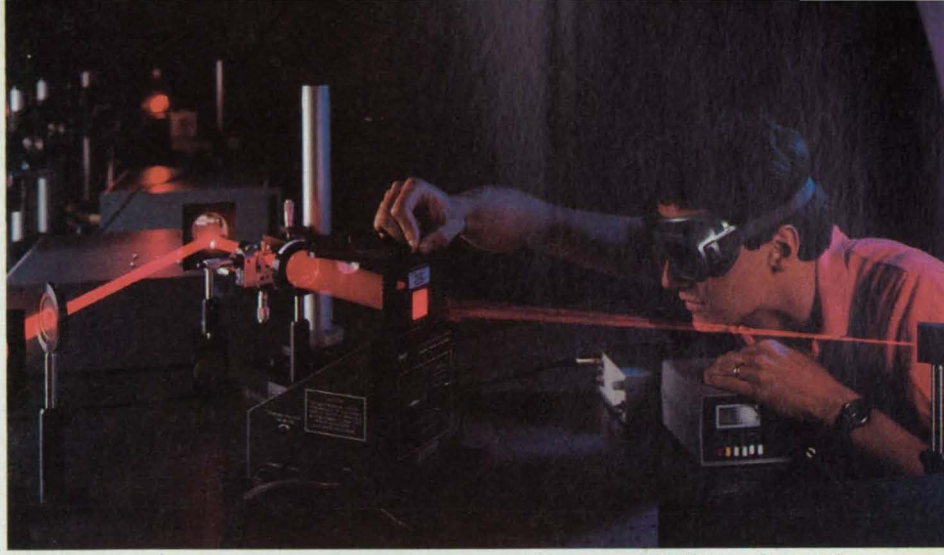


Photo courtesy of NASA Ames Research Center

A photonics investigator studying the use of optical neural networks for pattern recognition applies holography to redirect input laser beams.

Hybridizing machine learning with fuzzy logic yields control systems with human-like flexibility and robustness. They can automatically fine-tune their operation and learn from experience. "Any NASA control system currently manned by humans, on the ground or in space, is a candidate for fuzzy control," said Hamid Berenji, a specialist in the field. Earthbound applications for fuzzy control, such as camera autofocusing systems, will benefit from extensions and refinements of the technology.

Increasing the machines' autonomy does not preclude or even limit human-machine interaction. "We're not trying to remove the scientist, but rather to provide him with a competent aide who will free him from grunt work," said research scientist Mark Drummond. Among the many attributes of these "machine partners" are self-maintenance for extended periods and error tolerance by recognizing and resolving both human- and machine-induced errors.

Spinoff Potential

For space missions, automation can cut costs by reducing required ground personnel and training. It can increase scientific productivity by leaving more time for experimentation and providing swift and thorough data analysis. Further, it can increase the probability of a successful mission by assuming such tasks as fault management.

Advances in automation also offer applications closer to home. Benefits to the aeronautics industry will include flight deck automation and use of knowledge-based systems to improve air traffic control. In the future, intelligent machines will perform complex medical diagnoses and microsurgery, low-risk nuclear system monitoring and control, and environmental hazard detection.

One spinoff already paying dividends is AutoClass, a software package employing a Bayesian approach to perform automatic data analysis by classification. It has been used in such disparate fields as cancer epidemiology and criminology, and has potential for more accurate global climate modeling and ground cover mapping using remote sensing data. "We would like to see AutoClass integrated into large-scale statistics packages," said Peter Cheeseman, one of the software's developers.

Real-time, constraint-based scheduling methods developed for telescope observation scheduling and spacecraft mission planning also hold commercial potential. Efficient but flexible scheduling is crucial in industrial processes where many of the same optimization criteria apply. Package delivery services must coordinate transportation with maintenance while adapting to external factors such as inclement weather. Likewise, manufacturers must coordinate their machine resources with human operators to meet job deadlines.

Linked By Light

The more complex the machines' abilities, the greater the need for collaborative development. ASRF personnel are fully-interconnected by a state-of-the-art fiber optic communication network that allows various types of high-performance workstations to be coupled and decoupled at will. As the ASRF databus network grows and speeds up, it will support more and bigger projects. "In the past, you spent your first year of a project and most of your money just getting set up," said Edward Chevers, deputy chief of the Information Sciences Division. "But you don't build a wind tunnel every time you need one—now we won't have to build

individual networks for individual projects either." The fiber optic system will aid in the remote coaching of astronauts conducting space experiments. The coaching will comprise video and computer conferencing and document sharing, all in real time. "Now we can really distribute nodes for testing instead of pretending," said research scientist Sherry Chuang. According to Chuang, remote coaching also could be applied in education for interactive remote teaching, and to link medical experts in different locations for complicated surgical procedures.

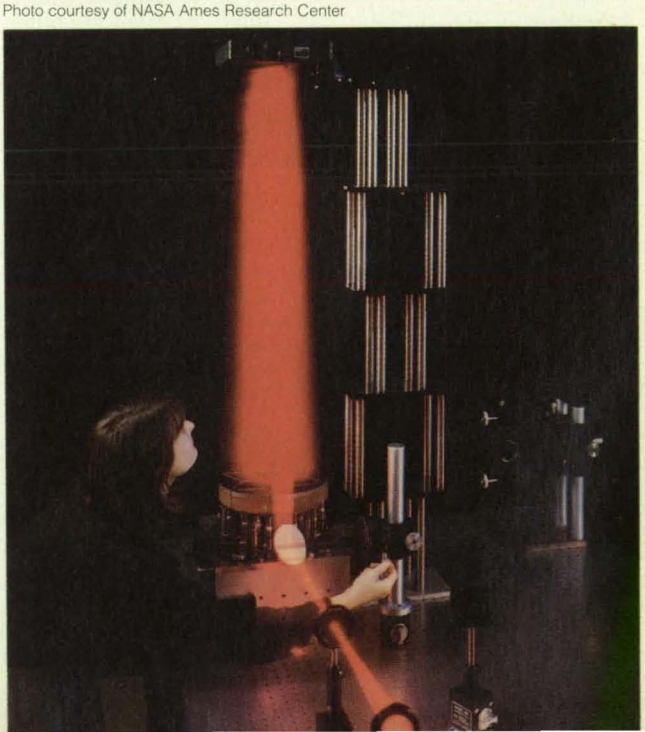
The ASRF was built adjacent to the Human Performance Research Laboratory (HPRL) to facilitate the synchronization of humans and machines. A 12,000-square-foot high-bay area, shared by the two facilities, houses a Station Thermal Control system mini-test bed and a human-machine integrated systems test bed. "We're in electronic as well as physical proximity," said Charles Jorgensen, chief of the Computational Systems Research Branch. "A person wearing a virtual reality helmet in an HPRL lab is connected to our robotics lab—the person virtually moves something, and the robot over here actually moves it."

Butler Hine, a robotics specialist, is excited about the potential for collaboration: "The enlarged robotics lab allows us to run more experiments simultaneously." The lab's denizens include a team of mobile robots. Among the new equipment is a 10'x 10' granite table weighing 20 tons for 0 g experiments on a 2D plane. Robots float on a frictionless cushion of air above the table for docking simulations.

The ASRF brings new capabilities to an array of projects."It allows us to edit and debug software in-house, and then to conduct simulations with live prototypes," said Brian Glass of the Autonomous Guidance, Navigation, and Control Systems Group. The group developed an automatic monitoring system for space shuttle thermal control that could be applied to large electromechanical systems such as those in refineries and power plants. An expansion of the system will allow the Search for Extraterrestrial Intelligence (SETI) Microwave Observing Project to operate for weeks with minimal supervision. ❑

For more information about the ASRF and its capabilities, contact: Dr. Henry Lum, Jr., Ames Research Center, Mail Stop 269-1, Moffett Field, CA 94035-1000.

A segmented mirror provides a test bed for the application of analog optical processing to high-speed control problems.
Photo courtesy of NASA Ames Research Center



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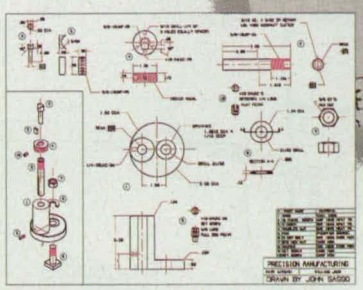

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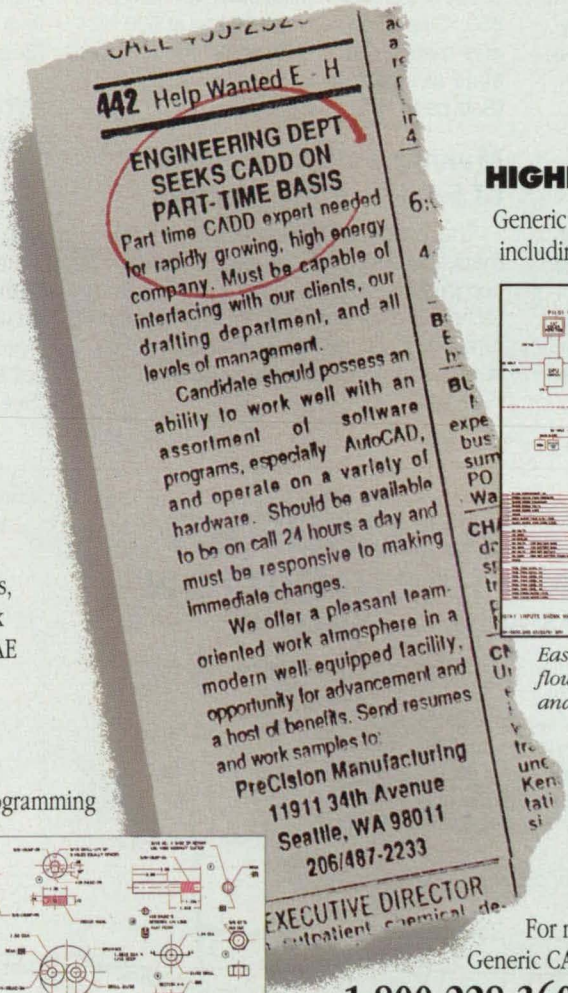

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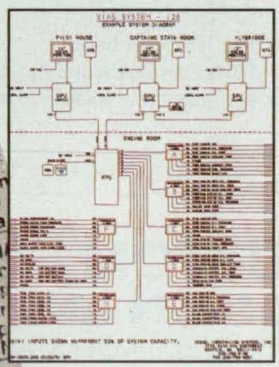

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New Product Ideas

New Product Ideas are just a few of the many innovations described in this issue of *NASA Tech Briefs* and having promising commercial applications. Each is discussed further on the referenced page in the appropriate section in this issue. If you are interested in developing a product from these or other NASA innovations, you can receive further technical information by requesting the TSP referenced at the end of the full-length article or by writing the Technology Utilization Office of the sponsoring NASA center (see page 16). NASA's patent-licensing program to encourage commercial development is described on page 16.

Regenerative Hydride Heat Pump

A proposed chemisorption heat pump would feature regenerative heating and a single circulation loop. The cooling coefficient of the pump, expected to be about 0.9, is 40 to 50 percent greater than that of the present hydride pumps. Using hydrogen as the working fluid, the pump would not be harmful to the ozone layer.
(See page 90)

Solid-State Imaging Device With Carbon Film

The performance of a solid-state imaging device can be enhanced by coating the front surface with a thin film of carbon or diamondlike carbon. The film acts as an antireflection coat and helps dissipate undesired static electric charges accumulating on the surface.
(See page 18)

Glass-Derived Superconductive Ceramic

A glass composition $Bi_{1.5}Pb_{0.5}Sr_2Ca_2Cu_3O_x$ annealed for 243 hours at 840 °C demonstrated a superconducting transition temperature of 107.2 K. Specimens of this material annealed between 500 and 850 °C became semiconducting at 500 °C and metallic in the normal-conductivity state at higher temperatures.
(See page 62)

Making Thin Laminae of Frozen Alloy Slurries

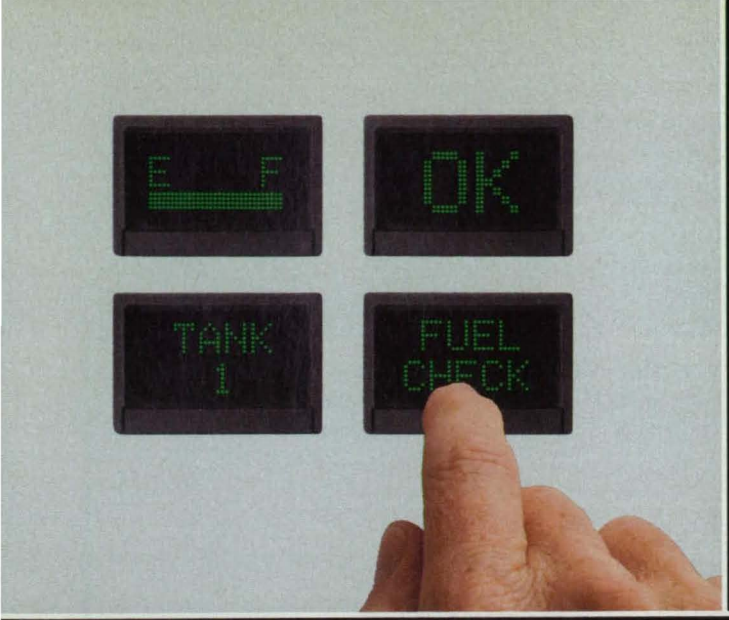
These laminae, interspersed with fiber mats, can be used to make metal/fiber composites. Appropriately modified, the technique may be adapted in the manufacture of future automobile engines or components that include molded ceramics.
(See page 103)

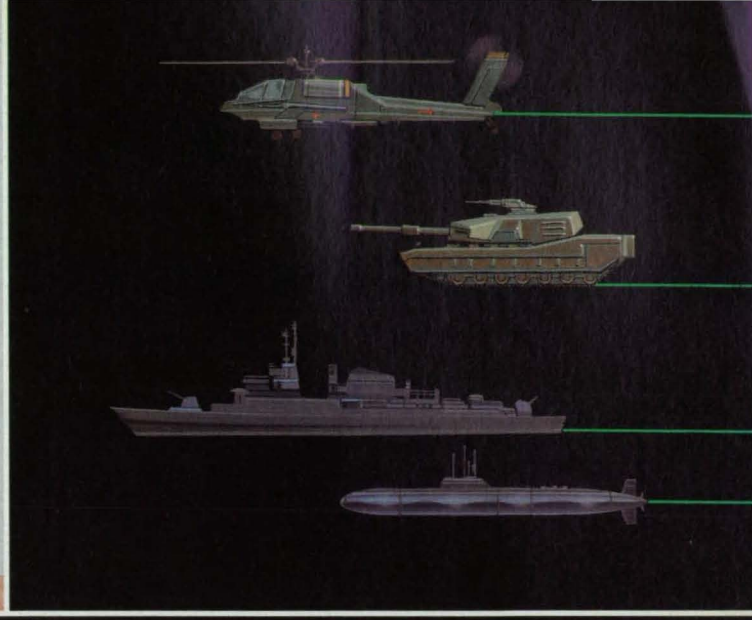
Making Positive Electrodes for Sodium/Metal Chloride Cells

Sintered nickel plaques have been impregnated with nickel chloride to form cathodes for these cells. The resulting cathodes show high coulombic yields at high current densities and suffer very little loss on charge/discharge cycling.
(See page 57)

White-Light, Dispersed-Fringe Interferometric Keratometer

A proposed keratometer would operate in a "snapshot" mode, requiring no scanning and no need to immobilize the patient's eye. Other than medical assessments of human corneas, the instrument could be used to measure the shapes of lenses and of other spherical and aspherical surfaces.
(See page 47)





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We've outlined below NASA's TU Network—named the participants, described their services, and listed the individuals you can contact for more information relating to your specific needs. We encourage you to make use of the information, access, and applications services offered by NASA's Technology Utilization Network.

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Dr. William Gasko
Center tor Technology Commercialization
Massachusetts Technology Park
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(508) 870-0042

MID-ATLANTIC

Ms. Lani S. Hummel
University of Pittsburgh
823 William Pitt Union
Pittsburgh, PA 15260
(412) 648-7000

SOUTHEAST

Mr. J. Ronald Thornton
Southern Technology Application Center
University of Florida
College of Eng.
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If you represent a public sector organization with a particular need, you can contact NASA's Application Team for technology matching and problem solving assistance. Staffed by professional engineers from a variety of disciplines, the Application Team works with public sector organizations to identify and solve critical problems with existing NASA technology. **Technology Application Team, Research Triangle Institute, P.O. Box 12194, Research Triangle Park, NC 27709; *Dr. Doris Rouse, Director,* (919) 541-6980**

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If you need further information about new technologies presented in NASA Tech Briefs, request the Technical Support Package (TSP). If a TSP is not available, you can contact the Technology Utilization Officer at the NASA Field Center that sponsored the research. He can arrange for assistance in applying the technology by putting you in touch with the people who developed it. If you want information about the patent status of a technology or are interested in licensing a NASA invention, contact the Patent Counsel at the NASA Field Center that sponsored the research. Refer to the NASA reference number at the end of the Tech Brief.

Ames Research Ctr.
Technology Utilization Officer:Geoffrey S. Lee
Mail Code 223-3
Moffett Field, CA 94035
(415) 604-4044
Patent Counsel:
Darrell G. Brekke
Mail Code 200-11
Moffett Field, CA 94035
(415) 604-5104

Lewis Research Center
Technology Utilization Officer: Anthony F. Ratajczak
Mail Stop 7-3
21000 Brookpark Road
Cleveland, OH 44135
(216) 433-2225
Patent Counsel:
Gene E. Shook
Mail Code LE-LAW
21000 Brookpark Road
Cleveland, OH 44135
(216) 433-5753

John C. Stennis Space Center
Technology Utilization Officer: Robert Barlow
Code HA-30
Stennis Space Center, MS 39529
(601) 688-2042

John F. Kennedy Space Center
Technology Utilization Officer: Thomas M. Hammond
Mail Stop PT-PMO-A
Kennedy Space Center, FL 32899
(407) 867-3017
Patent Counsel:
Bill Sheehan
Mail Code PT-PAT
Kennedy Space Center, FL 32899
(407) 867-2544

Langley Research Ctr.
Technology Utilization Officer: Joseph J. Mathis, Jr.
Head, TU & AO Office
Mail Stop 200
10 West Taylor Road,
Hampton, VA 23665-5225
(804) 864-2484
Patent Counsel:
Dr. George F. Helfrich
Mail Stop 143
9A Ames Road,
Hampton, VA 23665-5225
(804) 864-3221

Goddard Space Flight Center
Technology Utilization Officer: Donald S. Friedman
Mail Code 702.1
Greenbelt, MD 20771
(301) 286-6242
Patent Counsel:
R. Dennis Marchant
Mail Code 204
Greenbelt, MD 20771
(301) 286-7351

Jet Propulsion Lab.
NASA Resident Office
Technology Utilization Officer: Arif Husain
Mail Stop 180-801
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-4862
Patent Counsel:
Thomas H. Jones
Mail Code 180-801
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-5179
Technology Utilization Mgr. for JPL: Dr. Norman L. Chalfin
Mail Stop 156-211
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-2240

George C. Marshall Space Flight Center
Technology Utilization Officer: Ismail Akbay
Code AT01
Marshall Space Flight Center,
AL 35812
(205) 544-2223
Fax (205) 544-3151
Patent Counsel:
Robert L. Broad, Jr.
Mail Code CC01
Marshall Space Flight Center,
AL 35812
(205) 544-0021

Lyndon B. Johnson Space Center
Technology Utilization Officer: Dean C. Glenn
Mail Code IC-4
Houston, TX 77058
(713) 483-3809
Patent Counsel:
Edward K. Fein
Mail Code AL3
Houston, TX 77058
(713) 483-4871

NASA Headquarters
Technology Utilization Officer: Leonard A. Ault
Code CU
Washington, DC 20546
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If You Have a Question..**NASA Center For AeroSpace Information** can answer questions about NASA's Technology Utilization Network and its services and documents. The CASI staff supplies documents and provides referrals. Call, write or use the feedback card in this issue to contact: **NASA Center For AeroSpace Information,** Technology Utilization Office, P.O. Box 8757, Baltimore, MD 21240-0757. *Walter M. Heiland, Manager,* (410) 859-5300, Ext. 245.

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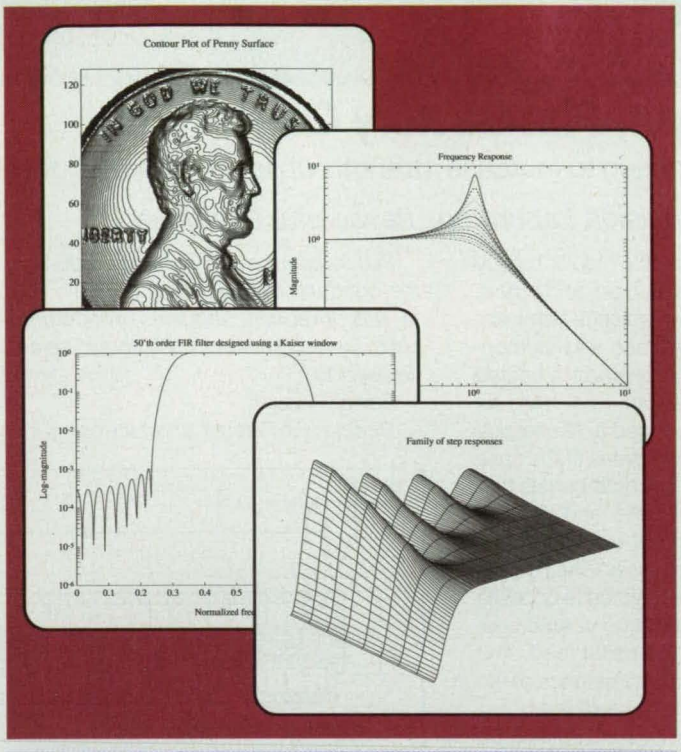

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A prototype of the case was demonstrated by using it to construct a sealed lead/acid bipolar battery in which six stacked flat cells produced a 12-volt output (see figure). The end plates of the case are made of fiber honeycomb panels that restrain the stacked cells and prevent them from being warped or distorted by internal and external stresses. The positive and negative terminals, located at opposite edges of the case, are made of solid copper rods instead of the usual lead. The weight and the electrical resistance of the copper are less than those of lead.

This work was done by John J. Rowlette of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 66 on the TSP Request Card.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

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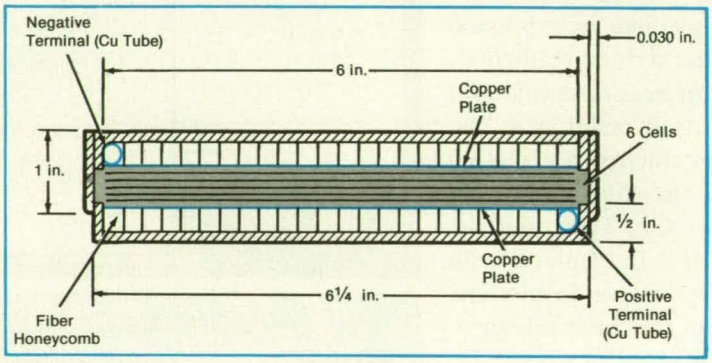
Refer to NPO-17605, volume and number of this NASA Tech Briefs *issue, and the page number.*



This **Cross Section of the Case** emphasizes its low ratio of height to width. The number of cells in the stack can be reduced or increased; the height will shrink or grow accordingly.

Solid-State Imaging Device With Carbon Film

The film reduces Fresnel reflections and dissipates static electric charges.

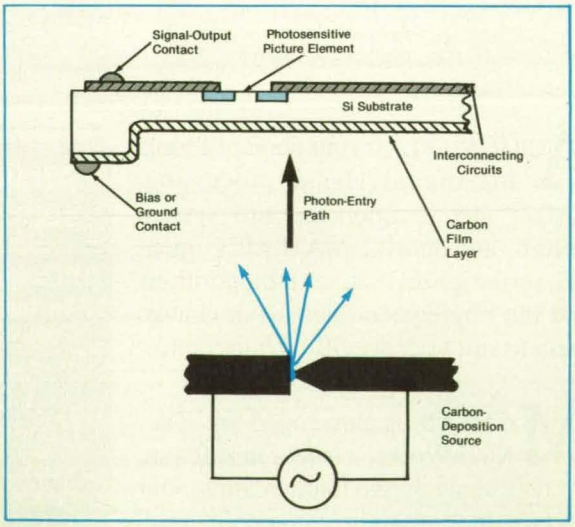
NASA's Jet Propulsion Laboratory, Pasadena, California

The performance of a solid-state imaging device (e.g., a charge-coupled device) can be enhanced by coating the surface through which photons enter with a thin film of carbon or diamondlike carbon. The film is beneficial in two ways: it acts as an antireflection coat, and it helps to dissipate undesired static electric charges that would otherwise accumulate on the surface.

Typically, a solid-state imaging device resides on a silicon substrate, and light is directed into the substrate through the back surface — that is, the surface opposite the one that holds the circuitry. An antireflection coat is desirable because the relatively high index of refraction of silicon gives rise to large Fresnel reflections of the incident light.

Some incident photons give rise to photoelectrons that are ejected from the surface, and because the electrical resistivity of the silicon substrate is high, this phenomenon causes the undesired accumulation of positive charges on the surface. The accumulated charges can reach levels great enough to alter the desired transfers of charges among the picture elements of the imaging device. Metallic films have been deposited on back surfaces of such devices in the attempt to conduct static charges away. However, metal films are disadvantageous in several ways: some metals diffuse into silicon, others absorb gases and behave anomalously, and most absorb photons, attenuating the light on its way to the sensing elements.

Carbon is a good choice for the back-surface film for three reasons: (1) It is sufficiently electrically conductive to drain away the static charges but not so conductive as to attenuate light severely when



Carbon is Evaporated onto the back surface of a solid-state imaging device. The carbon film acts as an antireflection and antistatic coat.

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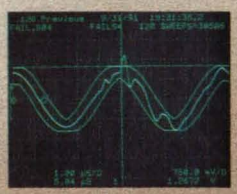

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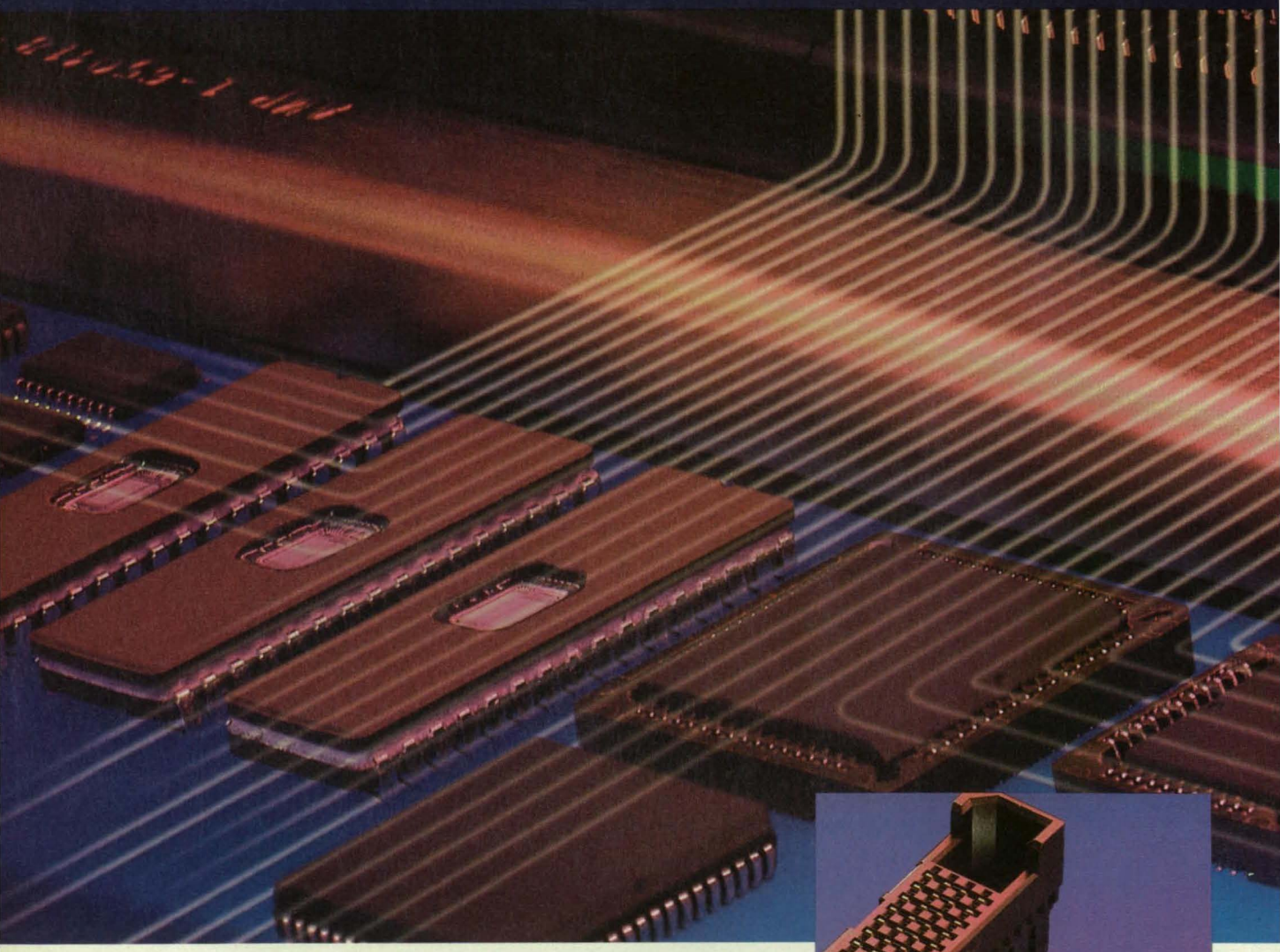

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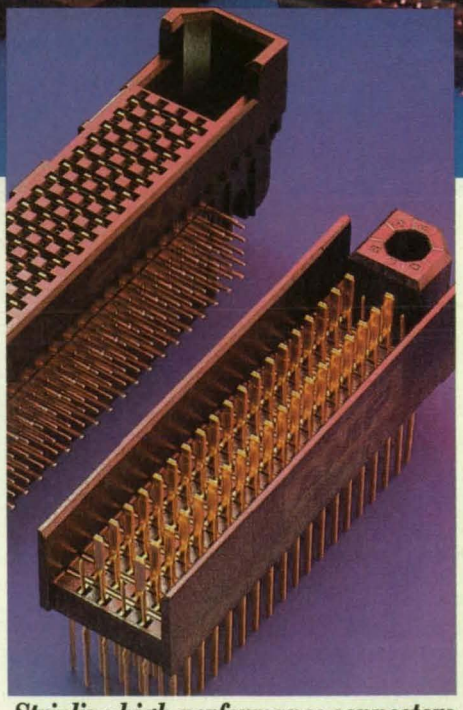

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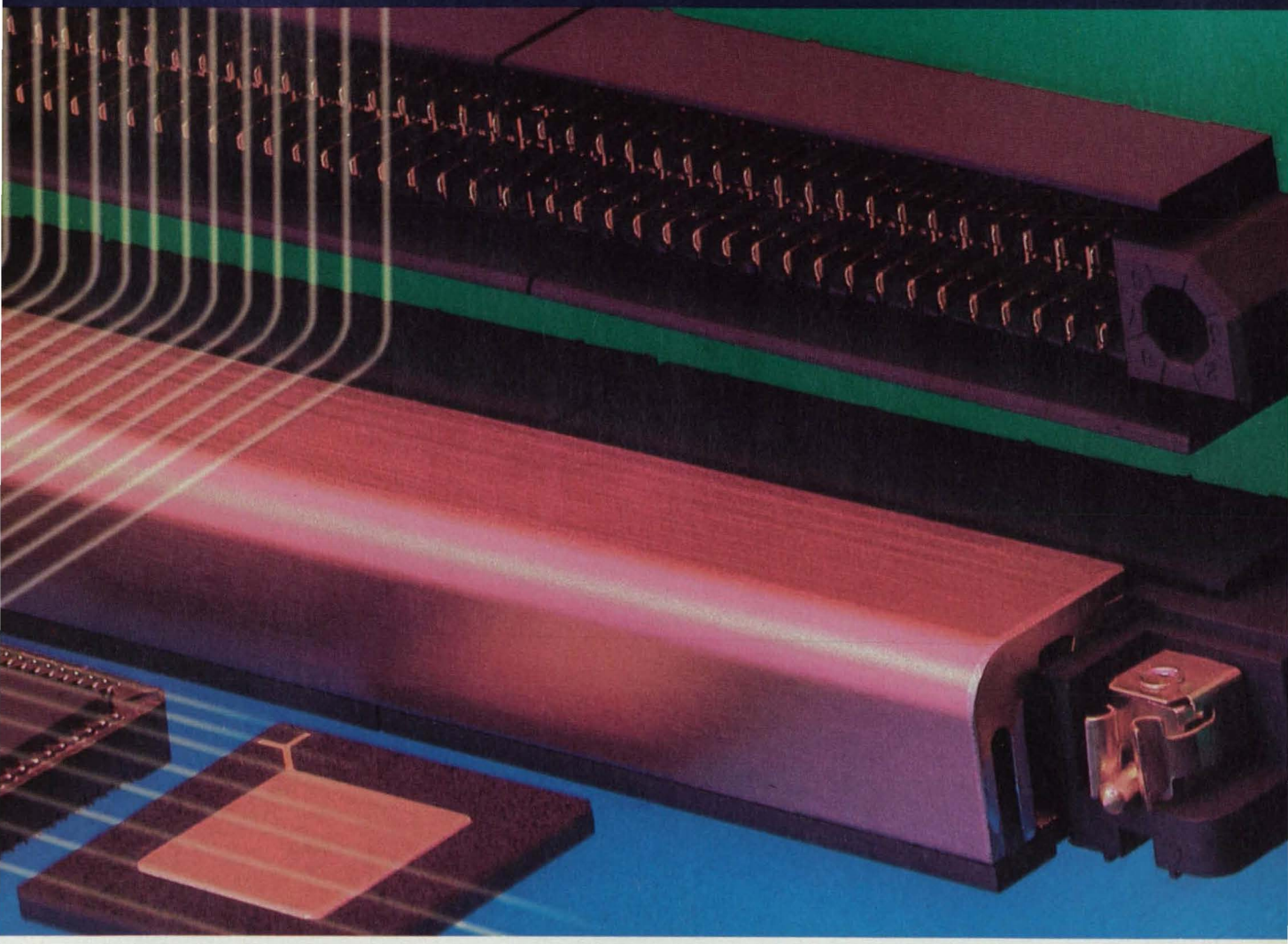

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deposited in thin layers. (2) Its index of refraction approximates the square root of the index of refraction of silicon, which is the optimum value for an antireflection coat. (3) It is chemically inert at the operating temperatures of the imaging device.

Carbon can be deposited on an imaging device by any of a number of established methods, and preferably by evaporation (see figure). The carbon film will be maximally effective as an antireflection coat if its thickness is an odd integral multiple of a quarter wavelength of the incident light (preferably ¼ or ¾ wavelength). In contrast, a typical metal film thicker than 1,000 Å would be opaque at most wavelengths.

This work was done by Robert E. Frazer of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 101 on the TSP Request Card.*
NPO-18201

Faster Computation of Far Fields of Dish Antennas

A modified Zernike-polynomial approach reduces the number of terms in the numerical integration.

NASA's Jet Propulsion Laboratory, Pasadena, California

A method of computing the far electromagnetic field radiated by a paraboloidal-dish-reflector or other circular antenna incorporates an improved series expansion and numerical-integration scheme. In comparison with prior methods, this one yields greater or equal accuracy with fewer terms in the series expansion and fewer sampling points across the aperture and, consequently, less computation. In a representative calculation of the far field of an offset-reflector antenna, the computing time of this method was only about one-thirtieth that of prior methods (see figure).

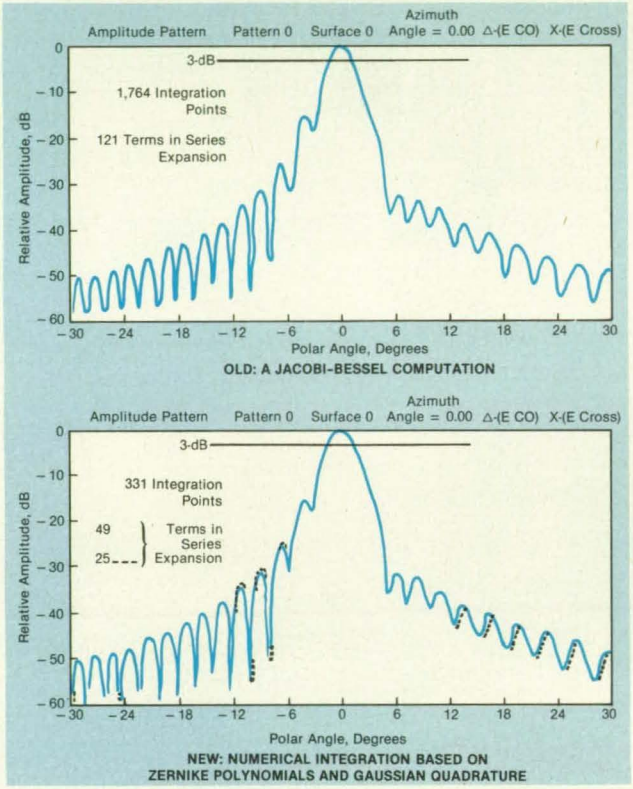
This method is one of few based on the Jacobi–Bessel-expansion concept, according to which the distribution of electrical current (or a physical-optics approximation thereof) across a circular aperture is represented by an infinite series (or a finite-series approximation) of basis functions that are orthogonal and integrable over the aperture. In this method, the basis functions are the circle polynomial functions introduced by Zernike in 1934. These functions are related to the well-known Bessel functions and the Jacobi hypergeometric polynomials. The Zernike-polynomial approach confers three important advantages:

(1) The infinite series equivalent to the radiation integral converges rapidly. The leading term in the series represents the pattern of radiation from an undistorted uniform-amplitude distribution across the aperture. Along the polar axis (in the direction of maximum intensity of the beam), the contribution of all the other terms in the series is zero. In other directions at small polar angles, the terms of higher order are the corrections over the leading term and in most practical cases are relatively small. Thus, relatively few terms are needed.

(2) The coefficients of the series expansion are independent of the observation angles. Therefore, once the coefficients are determined, the series can be rapidly computed for any observation point in the region of validity of the radiation integral.

(3) The Bessel-function terms, the calculation of which is relatively time-consuming, are inside the first of two summations in the series expansion and are decoupled from a second summation over harmonic exponential functions. This feature helps to reduce the computation time.

The coefficients of the series expansion are obtained by an improved numerical-integration scheme. For the integration over the azimuthal angle, the samples are taken at uniform intervals via the trapezoidal rule. The integration over the diameter is performed by use of a new Gaussian quadrature scheme. This scheme requires one-sixth to one-fourth the number of integration points needed in other currently available numerical-integration schemes developed for the same purpose.



Far-Field Radiation Patterns computed by a more-conventional Jacobi-Bessel series expansion and the new method are similar, but the new method requires fewer integration points and fewer terms in the series expansion.

This work was done by Vahraz Jamnejad of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 86 on the TSP Request Card.*
NPO-18055

Measuring Effects of Lightning on Power and Telephone Lines

A spherical antenna senses both horizontal and vertical fields simultaneously.

John F. Kennedy Space Center, Florida

A spherical antenna for the simultaneous measurement of all three components of an electric field has been developed for use in continuing research on lightning. Previous research has focused mainly on the larger, vertical components of electric fields caused by cloud-to-ground lightning. However, the smaller (by a factor of about 30), horizontal components of these electric fields can induce significant voltages and currents on such long, horizontal electrical conductors as overhead transmis-

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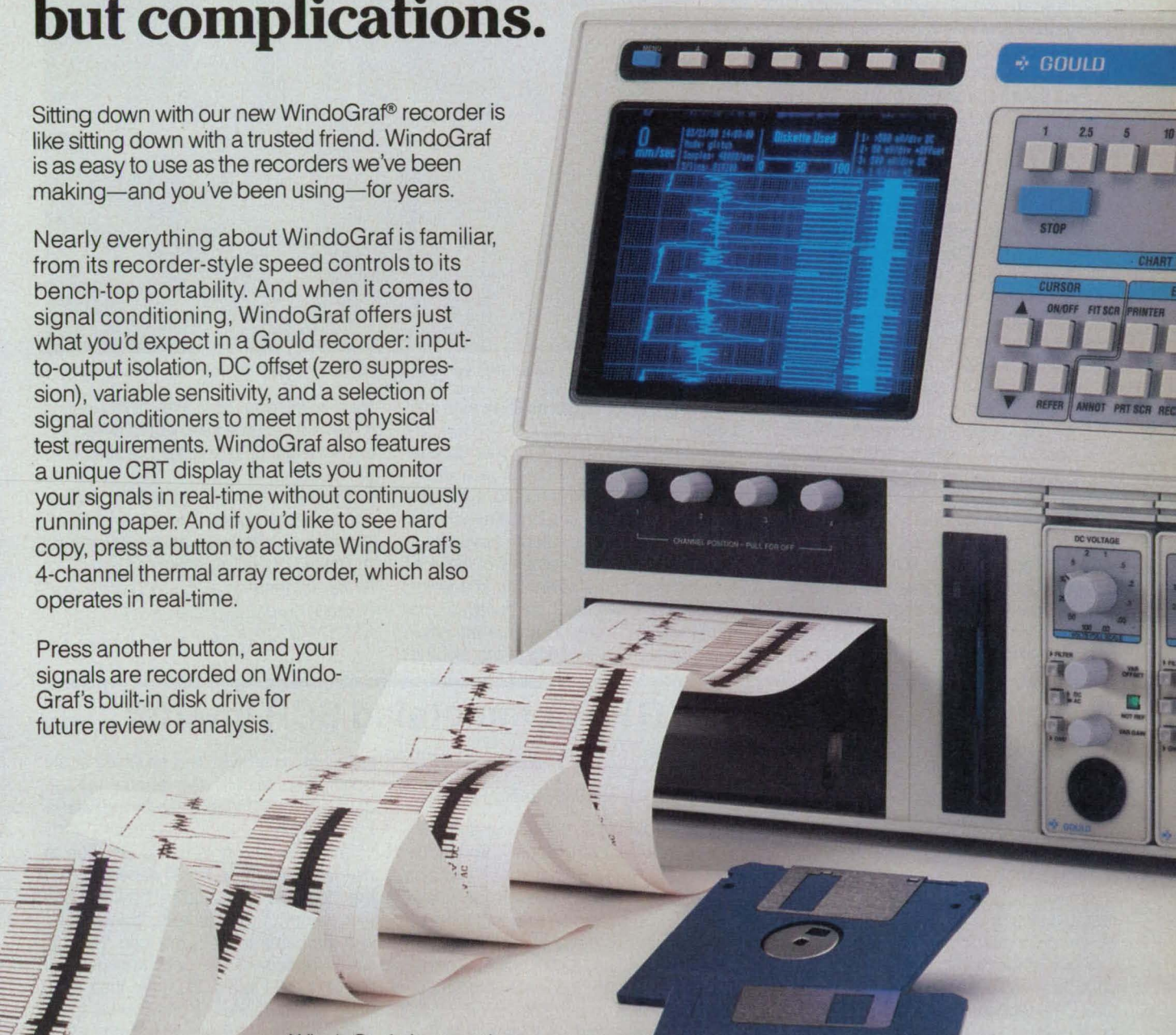

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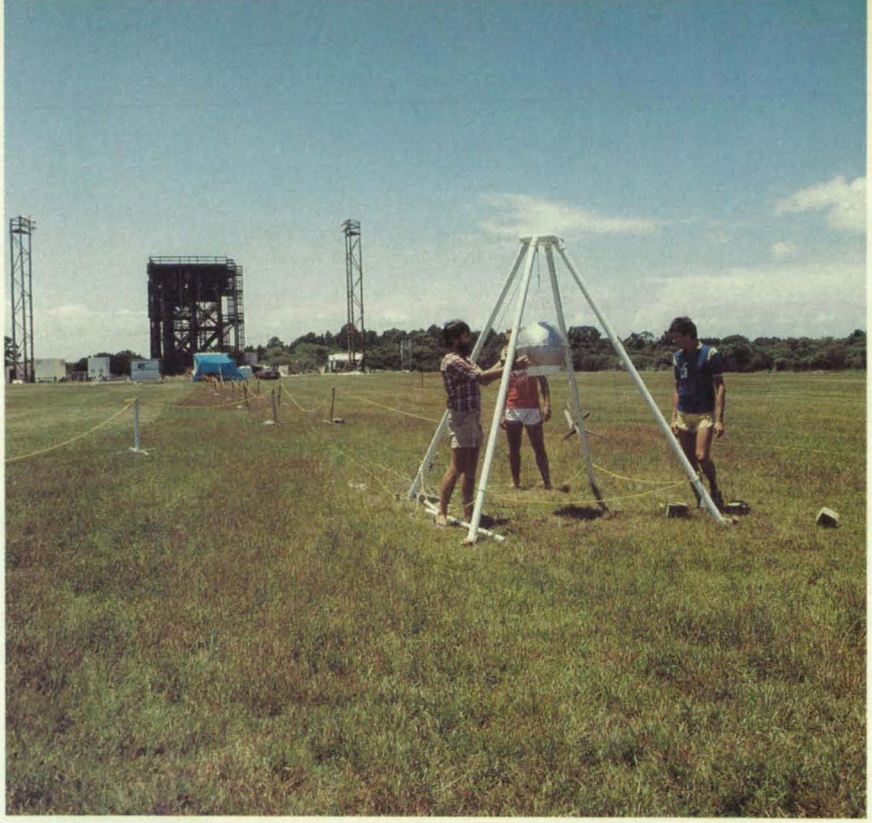
sion lines and buried cables. Because the horizontal components of an electric field depend on both the local electrical properties of the ground and on the vertical component, it has become necessary to measure all three components simultaneously in efforts to understand the effects of lightning on power lines and telephone lines.

The antenna includes a metallic sphere 45 cm in diameter, with insulated surface cutouts centered on three orthogonal axes. It is suspended about 1.5 m above ground from an insulating quadripod (see figure). The component of the electric field along each of the three orthogonal axes is sensed as a difference of potential between the two diametrically opposed surface cutouts that lie on that axis. Electronic circuits inside the sphere process the electric-field signals into light signals, which are transmitted via optical fibers to recording electronics. The recorded signals are processed by a computer with 20 MB of disk and tape storage.

The spherical antenna, which measures the "fast" components of the electric field (frequencies of a few megahertz) is used in conjunction with other equipment, including an antenna that measures the "slow" vertical component of the electric field; a microphone that senses thunder; cameras that make visual records, which help to locate the lightning; a magnetic-field sensor; optical sensors; and instruments that measure the speed and direction of the wind. To increase the frequency and regularity of measurements, lightning strokes can be triggered at or near a preset location in a manner reminiscent of Benjamin Franklin's famous experiment in which he flew a kite in thunderstorm. This is done by launching a small rocket trailing a wire into a cloud.



The **Spherical Antenna** measures vertical and horizontal electric fields simultaneously.

The spherical antenna has been used to measure the electric field near an unenergized power line 500 m long and 10 m high, induced by lightning striking 5 km or more away. These measurements have been correlated with measurements of the voltages induced in the power line, measurements of the electrical conductivity and permittivity of the ground, and a mathematical model of the coupling of the electric field into the power line. Preliminary results show fairly good agreement between the experimental data and the predictions of the model.

This work was done by William Jafferis of **Kennedy Space Center** *and E. M. Thompson, P. Medelius, M. Rubinstein, and A. Tftzeng of the University of Florida. For further information, Circle 63 on the TSP Request Card.*
KSC-11440

Regenerative Snubber for GTO-Commutated SCR Inverter

Loss of power would be reduced.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed regenerative snubbing circuit would be substituted for a dissipative snubbing circuit in an inverter based on silicon controlled rectifiers (SCR's) commutated by a gate-turn-off thyristor (GTO). (A snubbing circuit is one that limits the rate of change of voltage across a semiconductor component — in this case, the GTO.) The regenerative snubber is intended to reduce the loss of power that occurs in the dissipative snubber. The principal criteria in the conceptual design of the regenerative snubber are low cost, simplicity, and reliability.

The figure illustrates the inverter with the dissipative snubber and with two alternative versions of the regenerative snubber. In the dissipative snubber, the power lost equals $1/2CVf$, where V is the peak voltage to which the snubbing capacitance, C, is charged, and f is the rate of repetition of the GTO operating cycle. This loss is independent of the load and can exceed 1 percent of the peak throughput power.

The design of the regenerative snubber would be based on the principles of (1) automatic adjustments in response to changes in load and (2) the resonant transfer of energy from capacitor C to the input capacitor. The principle of operation can be summarized as follows: Let N_{de} and N_{ab} denote the number of turns in the windings of the clamping transformer between the terminals denoted by the respective subscripts, and let N_{fg} denote the number of turns in the smaller winding ($N_{fg} \leq 1/2N_{ab}$) added for the regenerative snubber. Let I_A = the anode current in the GTO at the instant when it is turned off, V_A = anode voltage across the GTO at the instant when it is turned off, and V_c = the instantaneous voltage across C. Assuming that the voltage across C at the instant of turnoff was zero, snubbing would occur, and initially the anode voltage across the GTO would rise at the rate of I_A/C.

This voltage and V_c would continue to rise to a value that would depend on V_A, the clamping ratio N_{del}/N_{ab}, the leakage inductance of the clamping transformer, and the parameters of the load. Then V_c would remain at this peak voltage until both the GTO and SCR_1 were fired. This firing would cause the energy in C to be resonantly discharged and transferred via winding *fg* to the input capacitor. Assuming that the resonant period of *LC* was less than the "on" time of the GTO, the current through SCR_1 would reach zero during the "on" time of the GTO, and SCR_1 would be commutated off.

It may not be necessary to add an external inductor to obtain the desired resonating inductance, *L*: the leakage inductance between *fg* and *ab* may suffice for this purpose. Where load currents vary over a wide range, it would be desirable

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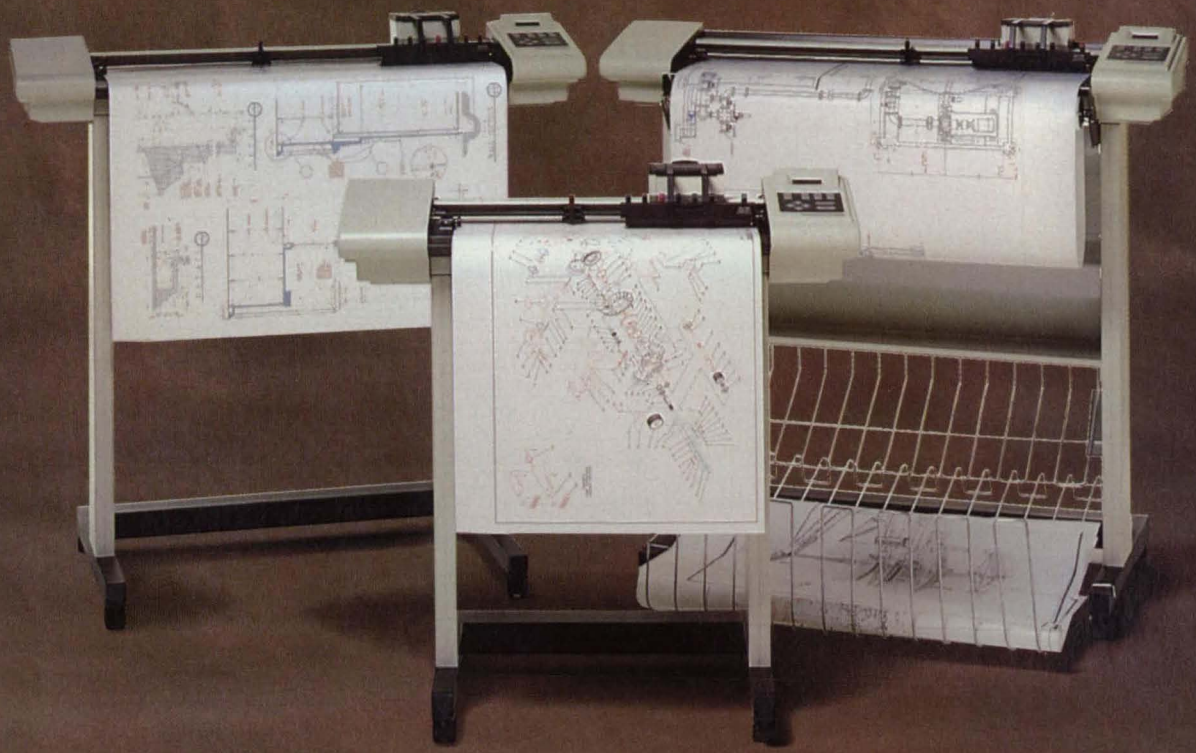

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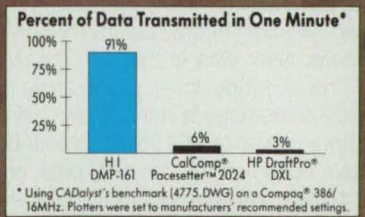

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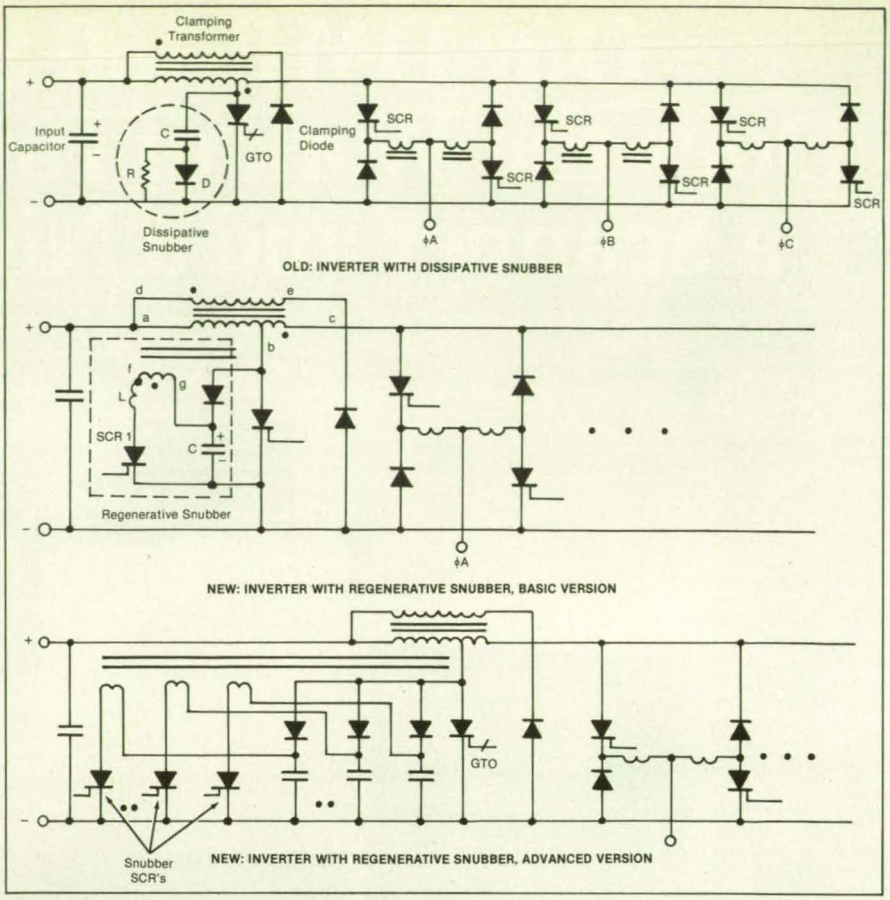

A **Regenerative Snubber** would resonantly transfer energy from the snubbing capacitor back to the input capacitor, thereby reducing the loss of energy that occurs in a dissipative snubber.

to effectively vary the value of *C*, possibly by the "advanced" scheme shown at the bottom of the figure. The effective value of *C* would depend on which one or combination of the snubber SCR's was fired.

This work was done by Wally E. Rippel and Dean B. Edwards of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 73 on the TSP Request Card. NPO-16865*

50 Mb/s, 220-mW Laser-Array Transmitter

Injection locking produces a single-wavelength, diffraction-limited, single-lobe beam.

Goddard Space Flight Center, Greenbelt, Maryland

A laser transmitter (see figure) based on injection locking produces a single-wavelength, diffraction-limited, single-lobe beam. The output stage of the transmitter is an array of laser diodes that would produce a non-diffraction-limited, multimode beam in the absence of injection locking.

The array acts as a gain-saturated slave amplifier for a high-quality beam injected from the master laser, a 30-mW single-stripe laser diode. When operated without modulation, this system can produce a 240-mW beam. With data encoded by 50 Mb/s non-return-to-zero modulation, peak beam power is 220 mW. This combination of peak power and modulation rate is among the highest yet achieved; scaling to even higher power may be possible. Single-stripe diode laser transmitters have achieved modulation rates of 1 Gb/s, but only at peak powers of 200 mW or less.

A transistor-based current-driving circuit modulates the output power of the laser array, rather than that of the master laser. If the master laser were to be modulated, the array would lase on its own (with its own inferior beam quality) when the master laser was in the "off" phase.

The 10-stripe laser diode array used in the transmitter is rated for a maximum output power of 500 mW in continuous-wave operation and for 1 W peak power in pulsed operation. Its emitting aperture is 100 μm × 1 μm. The beam from the master laser passes through an optical isolator and is focused by external optics to a spot 50 μm × 1 μm located at the emitting aperture of the laser array. The beam enters the array at an angle of incidence of 4° and makes several passes through the array, picking up power while suppressing the gain of the free-running modes of the array. The amplified beam

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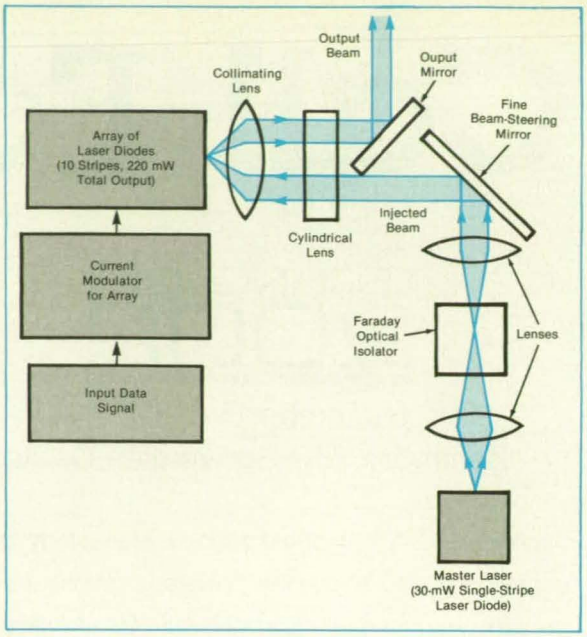
In the **Laser-Array Transmitter**, the single-mode diffraction-limited beam from the master laser injection-locks the array of laser diodes to produce a 220-mW beam of high quality.



leaves the array at an angle of -4°; i.e., separated by 8° from the incident beam. This separation enables the use of a mirror to deflect the emitted beam to the transmitter optics without interfering with the incident beam.

Transmitters of this type should be suitable for both free-space and optical-fiber communication systems. Because the beam from such a transmitter can be focused to a spot as small as 5 µm, such devices might be usable for reading and writing optical disks at increased information densities. The transmitter might also find application in remote sensing and ranging.

This work was done by Donald M. Cornwell, Jr., of **Goddard Space Flight Center**. *For further information, Circle 103 on the TSP Request Card.*
GSC-13382

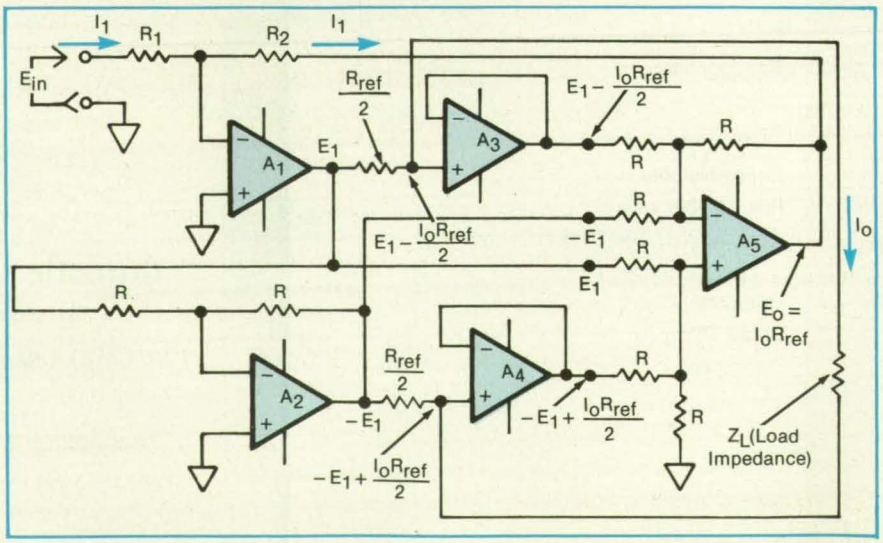
Differential Current Source

Effects of common-mode voltage are suppressed.

Goddard Space Flight Center, Greenbelt, Maryland

The circuit illustrated in the figure acts as a voltage-controlled current source that has a high-impedance floating differential output. It maintains a commanded current in a load, regardless of changes in the load impedance and regardless of any common-mode voltages (e.g., induced by stray magnetic coupling from powerlines) on the load. The circuit could be used, for example, to provide a constant excitation current to a germanium resistance thermometer or other transducer, the output voltage of which is to be sensed by a differential voltage amplifier.

The input control voltage E_{in} is coupled into the circuit via operational amplifier A_1. Acting in conjunction with input resistor R_1, feedback resistor R_2, and the rest of the circuit, operational amplifier A_1 produces whatever voltage E_1 is necessary to provide the positive-terminal output voltage that helps to drive the output current I_o through the load impedance Z_L. Together with its associated resistors, op-



The **Differential Current Source** produces output current I_o proportional to E_{in}, regardless of variations in Z_L and of common-mode voltages on the load.

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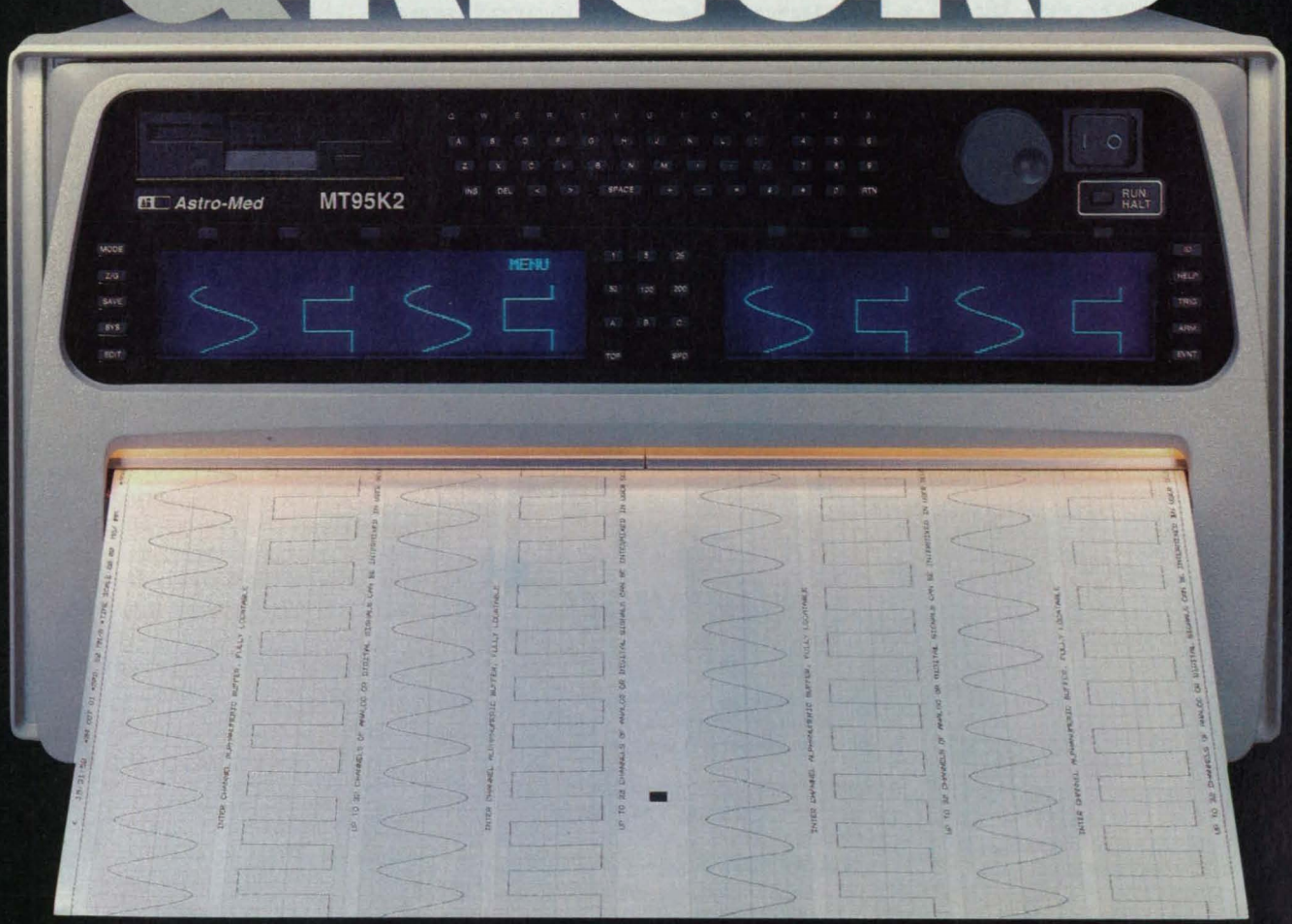

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erational amplifier A_2 acts as a unity-gain inverter to produce $-E_1$, which provides the negative-terminal output voltage that helps to drive I_o through Z_L. Operational amplifiers A_3 and A_4 are connected as voltage followers to isolate the reference resistors $R_{ref}/2$ from the low impedances of A_5 and its associated resistors.

Operational amplifier A_5 and its associated resistors act as a unity-gain differential voltage-summing circuit; specifically, one that sums the potential drops across the two reference resistors $R_{ref}/2$ to produce $E_o = I_o R_{ref}$. The input current $I_1 = E_{in}/R_1$ flows through R_2, so that $I_1 = -E_o/R_2$. Rearranging the foregoing equations,

$$I_o = E_o/R_{ref} = -I_1 R_2/R_{ref} = -E_{in} R_2/R_1 R_{ref}$$

That is, the output current depends only on the control input voltage and the resistances in the circuit.

To obtain the low noise that is essential in such applications as measuring the resistances of germanium resistance thermometers at a temperature of about 0.1 K, A_3 and A_4 should be low-noise junction field-effect-transistor (JFET) devices or bipolar devices preceded by low-noise JFET voltage followers. The resistors should be fabricated on the same substrate and mounted in good thermal contact so that all vary together with changes in temperature and ratios between resistances remain constant. For operation over a wide temperature range, it is particularly important that all the resistances labeled "R" in the figure vary together and that the ratio R_2/R_1 remain constant.

This work was done by John F. Sutton of **Goddard Space Flight Center**. *For further information, Circle 153 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Goddard Space Flight Center [see page 16]. Refer to GSC-13280.

FET's Perform Well at Cryogenic Temperatures

Transistors are designed for superior performance at low temperatures.

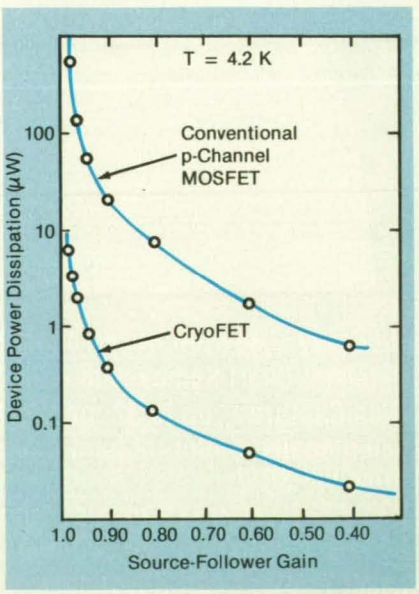
Ames Research Center, Moffett Field, California

New metal-oxide-semiconductor field-effect transistors were designed specifically for source-follower preamplifiers operating at liquid-helium temperatures in conjunction with infrared detectors. Known as CryoFET's, the new devices have potential applications ranging from astronomy to mineral exploration.

The CryoFET's were compared with conventional p-channel MOSFET's, Both devices were produced with the same geometries, the difference being in the doping. The MOSFET's were made with p diffusions for the source and drain on SiAs substrates. The CryoFET sources and drains were made with n-diffusions on the same kinds of substrates to take advantage of the low-temperature charge-carrier freezeout by operating in an enhancement mode. To find the best geometry and substrate resistivity for low-temperature operation, 16 combinations of gate width and length and 4 n-type substrate resistivities were tried.

The electrical characteristics of the CryoFET's and MOSFET's were observed at temperatures from 2.4 to 27 K. Properties measured include gate-to-source capacitance, current-versus-voltage characteristic curves, and gain and noise as a function of frequency with the devices connected as source followers and biased for a dc gain of 0.98.

Noise figures of CryoFET's were two to four times lower than those of the MOSFET's. At 4.2 K and a gain of 0.98, CryoFET power dissipation was hundreds of times lower (see figure). The superior dissipation and noise characteristics persisted up to 20 K. Gate-to-source threshold and



The **Power Dissipation Required for a Specified Gain** is plotted for two source followers — one using a CryoFET and the other a comparable MOSFET. The MOSFET consumes about 50 to 100 times as much power to achieve the same gain.

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source-offset voltages were lower in the CryoFET's, and while some MOSFET's showed considerable hysteresis in the current/voltage characteristic curves, the CryoFET's did not.

The lower thresholds and offsets should give the CryoFET's greater dynamic range and linearity than conventional MOSFET's at low temperatures and should facilitate pair balancing to reduce offsets in the output. Of course, the lower dissipation reduces the heat loading of the cryogenic system, thus extending the life, reliability, and performance of cryogenic infrared instruments.

This work was done by N, Sclar of Rockwell International Science Center for **Ames Research Center**. *Further information may be found in NASA CR-166321 [N82-22436], "Design, Production and Testing of Field Effect Transistors"*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700. ARC-11456

Eliminating Deadbands in Resistive Angle Sensors

Output would be continuous throughout a complete rotation.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed shaft-angle-measuring circuit would provide a continuous indication of the angle of rotation from 0° to 360°. The sensing elements would be two continuous-rotation potentiometers, and the associated circuitry would eliminate the deadband (ambiguous resistance and angle measurement) that occurs when the wiper contact of a potentiometer crosses the end contacts near the 0° position of the circular resistive element. An angle-measuring circuit of this type could be used, for example, in a valve-position indicator or a similar device in which long operating life and high angular precision are not required.

The two potentiometers would be ganged to the shaft and oriented in opposite phase; that is, when the shaft was at the 0° position of potentiometer B, it would be at the 180° position of potentiometer A. At shaft angles between the 90° and 270° positions of potentiometer A (from the 270° position through the 0°/360° deadband position to the 90° position of potentiometer B), the associated circuitry would select and process the output of potentiometer A. At shaft angles between the 90° and 270° positions of potentiometer B (from the 270° position through the 0°/360° deadband position to the 90° position of potentiometer A), the associated circuitry would select and process the output of potentiometer B. Thus, neither potentiometer would be used at angles within about 90° of its deadband.

The analog outputs of the potentiometers would be amplified and fed to a set of window comparators, which would help select one of these outputs (see Figure 1). The outputs of the comparators would be processed further by selection-logic circuitry, which would add hysteresis to prevent oscillations during transitions between potentiometers.

The output of the selected potentiometer would be digitized to obtain a binary representation of the angle. Whenever potentiometer B was selected, the most significant bit in the digitized output would be inverted (see Figure 2). The inversion would make the digitized output vary in a continuous (down to the least-significant bit) sequence from 0° to 360°

This work was done by Phil M. Salomon, Russell O. Allen, and Carl A. Marchetto of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 146 on the TSP Request Card. NPO-18123*

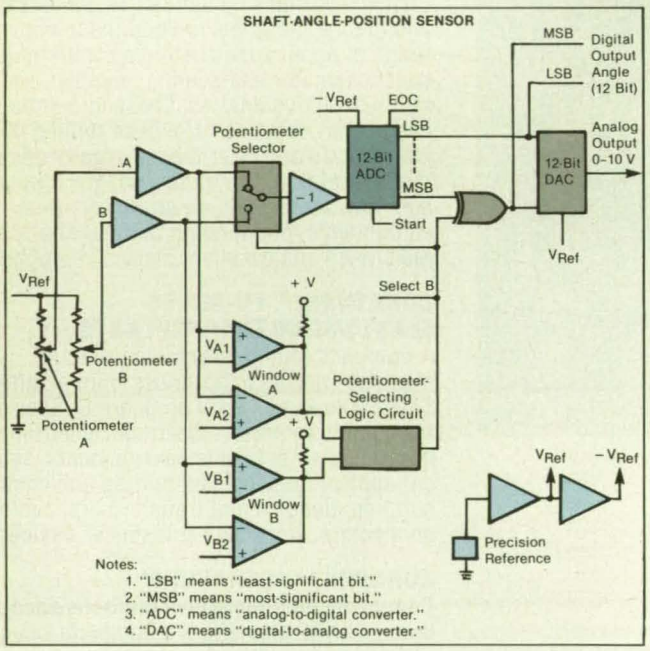

Figure 1. **Window Comparators** would select the output of one potentiometer or the other, in such a way as to avoid the deadbands of both.

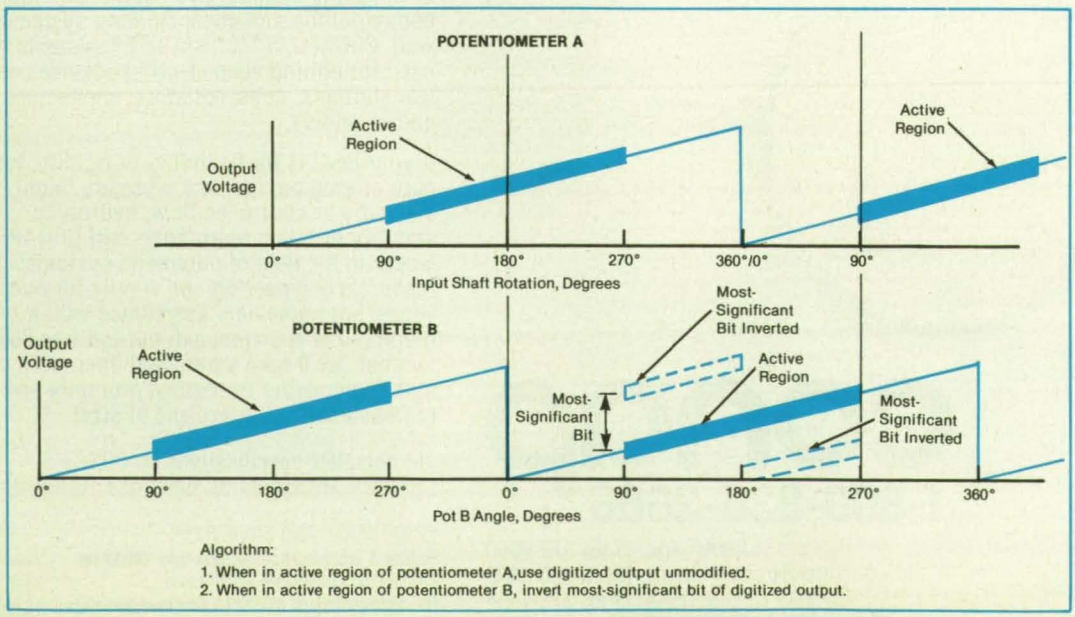

Figure 2. **To Make the Digitized Output Appear Continuous From 0° to 360°**, the most-significant bit would be inverted when potentiometer B was selected.

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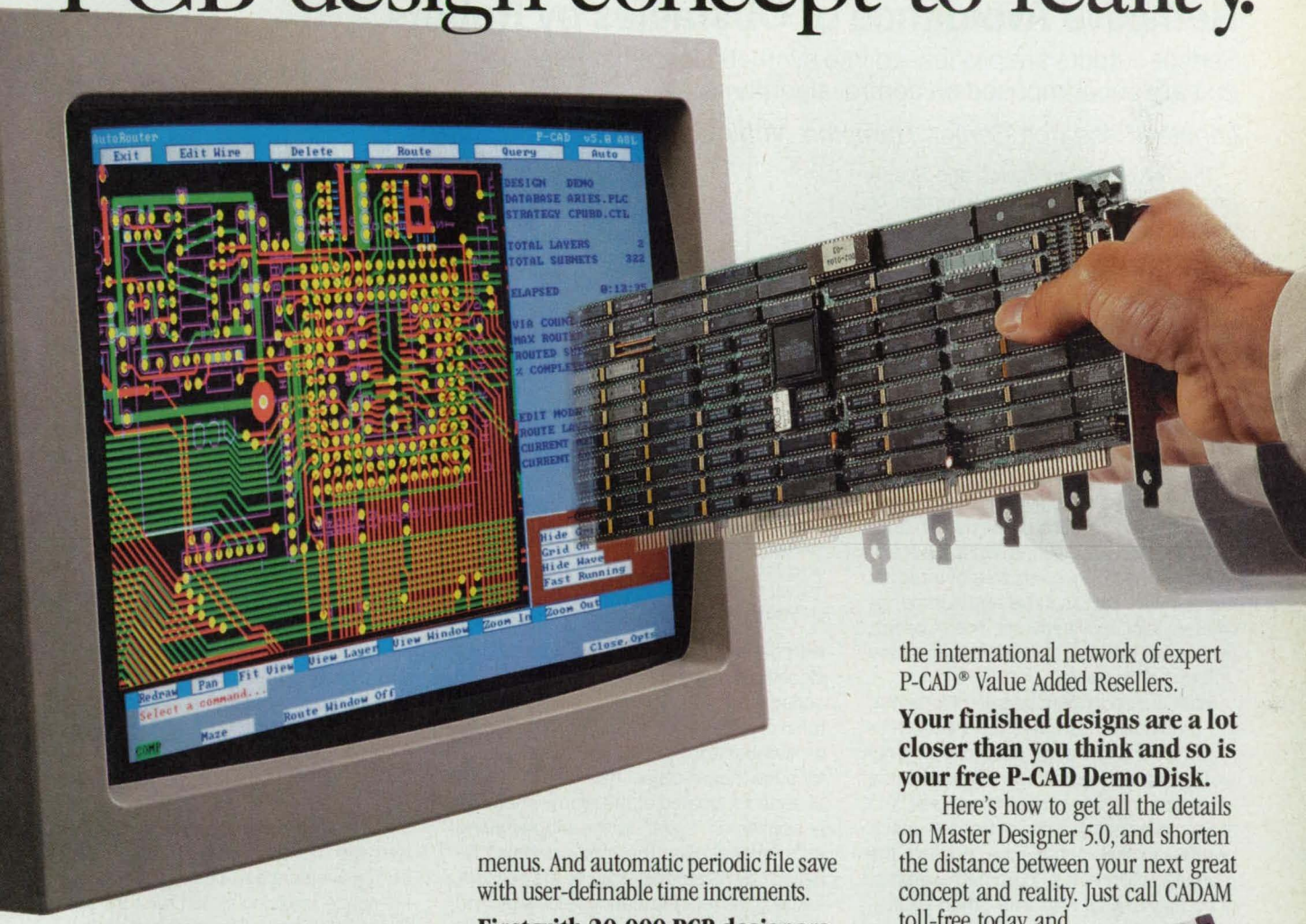

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Electronic Systems

Reflexive Avoidance of Obstacles by Robots

Sensor outputs are processed into synthetic force-field signals that are superimposed on control algorithms.

Langley Research Center, Hampton, Virginia

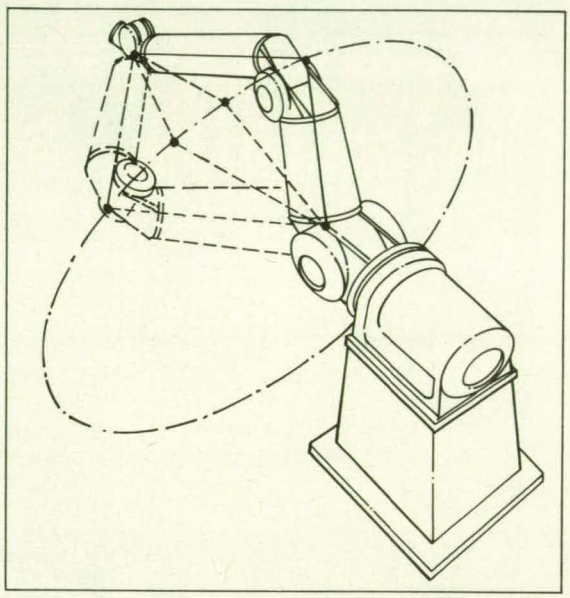
The National Aeronautics and Space Administration has identified a number of promising applications for advanced robots and telerobots in future space operations. The most sophisticated of these robots will be required to perform complex tool-handling tasks with dexterity nearly equivalent to that of humans while operating with a minimum of human intervention.

These telerobots will generally have more than six joints apiece operating under simultaneous, coordinated control. Seven is the minimum number of axes required in a mechanical manipulator to imitate the basic motions of the human arm, from the shoulder to the wrist. Like the human arm, a seven-degree-of-freedom manipulator can assume any number of different joint configurations, or arm poses, for a given position and orientation of the "hand," or toolpoint.

With one redundant degree of freedom, the manipulator arm has the freedom to reach around and avoid collisions with objects in certain locations in its workplace while it performs its programmed task. The more redundant degrees of freedom incorporated in the manipulator system, the more versatility it has. To perform extremely complex tasks with true "man equivalence," future space telerobots may eventually incorporate hundreds of degrees of freedom operating under coordinated control.

Research was conducted to develop a reflexive obstacle-avoidance system for kinematically redundant manipulators equipped with proximity sensors mounted on the manipulator arms to control the poses of the arms. Specific objectives of research projects included the evaluation of alternate proximity-sensor technologies, the development of algorithms to translate sensor data into penalty functions that represent obstacles, and the demonstration of a prototypical system. Proximity-sensor technologies were surveyed and evaluated for both Earth and space applications.

A seven-degree-of-freedom (dextrous) manipulator and a motion controller served as the laboratory test bed for interactions with sensors and the implementation of algorithms. Equations were developed and coded to modify dynamically the objective functions used by the standard redundant motion-control algorithm of the manipulator such that an object detected by arrays of sensors located at the elbow effectively applies a "force" to the elbow, along its rotational axis. The elbow is thus "repelled" by objects detected by the sensors, causing the robot to steer its elbow around the objects in the workspace automatically while continuing to move its tool along the commanded path without interruption.



An **Array of Sensors at the Elbow** of this robotic manipulator detects obstacles. The outputs of the sensors are processed into a synthetic "force field" around each obstacle. The algorithm that controls the manipulator uses the "force field" to maneuver the manipulator arm around each obstacle.

Signals transmitted by each sensor in the arrays mounted on the elbow to the control unit are processed to add vectorially the largest forces, as reflected by the closest objects, on either side of the manipulator and to apply the resultant force along the rotational axis of the elbow (see figure). This scheme enables the arm to center itself between objects detected on either side of the elbow joint or on both sides simultaneously. In addition, the forcing function varies exponentially with distance, so that objects detected at close range cause a much more rapid movement of the arm away from an impending collision. While this effort is aimed primarily at avoiding collisions with external objects detected in the workspace, the principle applies equally well to the detection and avoidance of collisions between different members of the manipulator itself.

The mathematical approach to the translation of proximity-sensor inputs into additional redundant control criteria is extensible to massively redundant systems of any topology. The more redundant the system, the more valuable sensor-driven reflexive avoidance of obstacles becomes. For space servicing systems like the NASA Flight Telerobotic Servicer, it may be impossible to perform the planned operations without such a system.

Also, the avoidance of collisions in real time is implemented as a critical safety subsystem. The FTS, for instance, has requirements for a means to ensure that the telerobot cannot injure an astronaut who inadvertently drifts into the working envelope, and to ensure that the telerobot cannot damage fragile spacecraft hardware by unplanned collisions. In addition, opportunities for the use of redundant robots in automated factories would be expanded substantially if a reflexive obstacle-avoidance system became commercially available. The use of off-line programming for redundant manipulators and associated work-cell-design time would be greatly reduced with an obstacle-avoidance system to select the poses of arms dynamically

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and without explicit programming intervention by the operator.

This work was done by Havard I. Vold, and James D. Farrell of Robotics Research Corp. for **Langley Research Center**. *No further documentation is available.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

James P. Karlen
Robotics Research Corp.
5400 DuPont Circle
Milford, OH 45150

Refer to LAR-14135, volume and number of this NASA Tech Briefs *issue, and the page number.*

Laser Scanner Tests for Single-Event Upsets

Irradiation by laser is substituted for the more-expensive irradiation by energetic heavy ions.

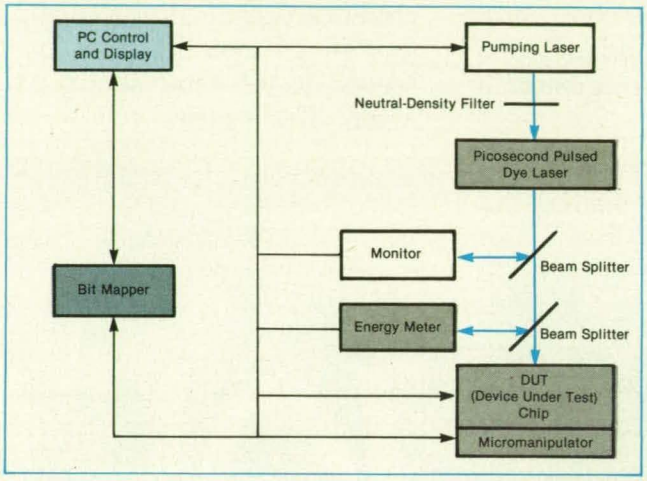
NASA's Jet Propulsion Laboratory, Pasadena, California

The microelectronic advanced laser scanner (MEALS) is an opto/electro/mechanical apparatus for nondestructive testing of integrated memory circuits, logic circuits, and other microelectronic devices. The MEALS is a multipurpose diagnostic system that can be used to determine ultrafast time response, leakage, latchup, and electrical overstress. Most notably, it can be used to simulate some of the effects of heavy ions accelerated to high energies to determine the susceptibility of a digital device to single-event upsets (changes in stored bits unaccompanied by significant permanent damage).

The MEALS is designed to overcome the main disadvantages of single-event-upset testing by irradiation with ions accelerated in cyclotrons, which are that such testing is expensive and time-consuming, the devices to be tested must be brought to the cyclotron, and the ion strikes cannot be directed to specific locations on the devices. In the MEALS, light from a picosecond pulsed dye laser is focused at selected locations in an integrated circuit to test for vulnerability of those locations to single-event upset, and the beam is scanned from one location to another in a controlled manner.

The MEALS is based on the principle that photons that have energies greater than the gap between the valence and conduction electron-energy bands of the semiconductor in the device under test can be absorbed, producing electron/hole pairs as charged particles do. The wavelength and energy of the laser beam can be adjusted to vary the effective depth of penetration of the photons to probe the layers of the circuit with some selectivity.

The device under test is mounted on a micromanipulator in the MEALS and connected to the MEALS power-supply and testing circuits. The device used for system development is a 256K DRAM which can be tested in either of two logic states: sensitive (all memory cells initially charged to the "one" state) or insensitive (all cells initially discharged to the "zero" state). Visible or infrared light from a tunable dye laser is focused to a spot <1.5 μm wide at the selected location while the output signal of the device is closely monitored by an optical bit mapper controlled by a computer (see figure). The computer also controls the micromanipulator to position the device relative to the laser spot, and it synchronizes the pulse time of the laser with the monitoring time of the optical bit mapper.



The **Microelectronic Advanced Laser Scanner** probes selected locations on an integrated memory or other circuit for susceptibility to single-event upsets. The probe is a laser beam focused to a small spot to simulate some of the effects of energetic heavy ions by generating electron/hole pairs at that spot.

Thus, the most-sensitive transistors and/or other microelectronic devices in an integrated circuit can be identified and plotted on an optical bit map. Such variables as the laser energy, the portion of laser energy deposited in the device under test, the threshold value of either of these energies that causes single-event upsets, the depth of penetration, and the location can also be plotted on an optical bit map and interpreted to explore methods to reduce susceptibility to single-event upsets.

Because of some fundamental differences between irradiation by laser and irradiation by energetic ions, one must exercise some caution in interpreting the results of tests on the MEALS. One difference is that the track of electron/hole pairs produced by an ion is only about 0.05 μm wide — much narrower than the laser beam and its track of electron/hole pairs. Another difference is that the density of charge carriers produced by the laser beam decreases approximately exponentially with depth of penetration, while that of an energetic ion does not. Still other differences involve energies and mechanisms of interaction with the semiconductor material and distributions of charge carriers.

This work was done by Quiesup Kim and George A. Soli of Caltech and Harvey R. Schwartz of Trend Western for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 57 on the TSP Request Card.*

NPO-18216

Single-Event-Upset Laser Scanner With Optical Bias

Additional steady illumination increases vulnerability to upset in the insensitive mode.

NASA's Jet Propulsion Laboratory, Pasadena, California

The light-assisted microelectronic advanced laser scanner (LAMEALS) is an augmented version of the microelectronic advanced laser scanner (MEALS) described in the preceding article, "Laser Scanner Tests for Single-Event Upsets." The only major difference is that in the LAMEALS, steady illumination from a helium/neon laser, argon-ion laser, and/or other source(s) is combined with the pulsed dye-laser illumination of the MEALS into a single illuminating beam (see figure). As in the MEALS, this beam is focused onto a small spot on the device under test. The

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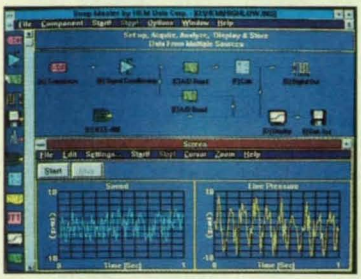

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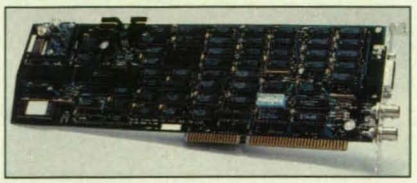
New Event Timing Controller



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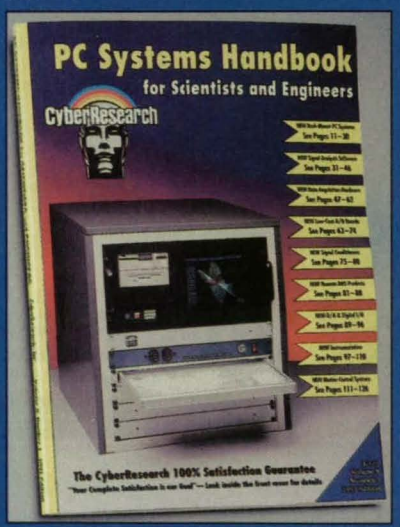

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Circle Reader Action No. 531

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#OIX 3010 Low-cost, Drawer-Mounted Rack-Mount Keyboard.....**$295**
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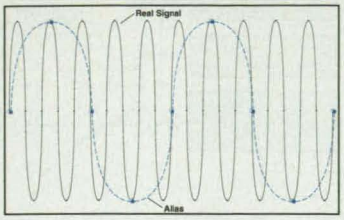

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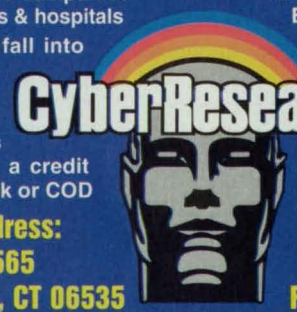

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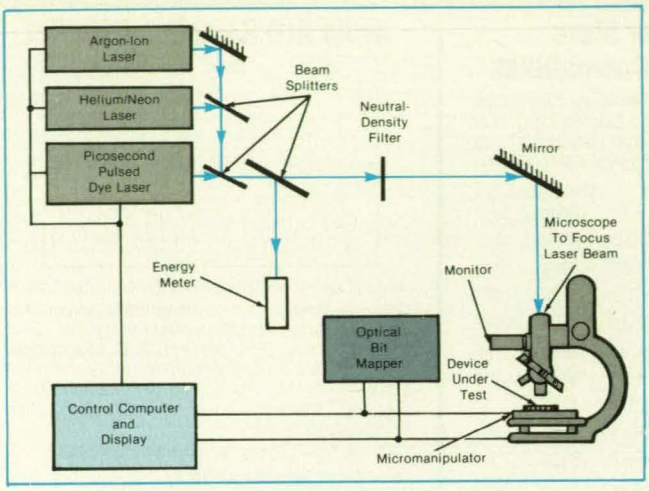
steady component of the illumination can be regarded as an optical bias. The response of the device under test to this bias can provide additional data to characterize the device.

Effects of optical bias were observed in tests of an n-type metal oxide semiconductor 256K dynamic random-access memory. When the memory was in the insensitive mode (all cells discharged to the "zero" state), the pulsed laser light alone below a certain intensity could not upset the memory. However, when an optical bias of about 20 kW/cm^2 (produced by focusing a 5-W, 632.8-nm steady laser beam) was applied to a storage capacitor in the memory, the pulsed laser light did cause upsets. In addition, it was found that the memory could be upset by the optical bias alone.



The **Light-Assisted Microelectronic Advanced Laser Scanner** adds steady illumination (optical bias) to the probing spot of light on the device under test. In other respects, it is essentially the same as the microelectronic advanced laser scanner described in the preceding article.

This work was done by Quiesup Kim of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 84 on the TSP Request Card. NPO-18217*

Automatic Pilot for Flight-Test Maneuvers

Experimental maneuvers can be repeated accurately.

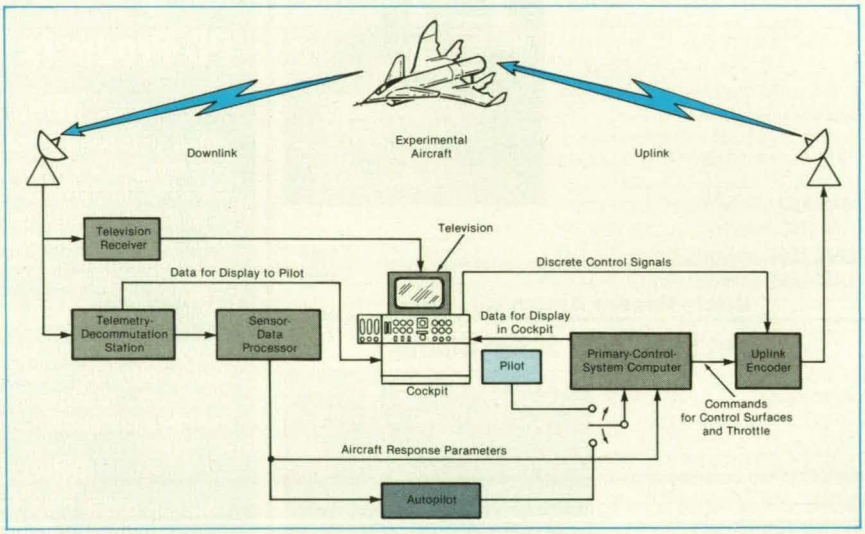
Ames Research Center, Moffett Field, California

An autopilot controls a highly maneuverable, remotely piloted aircraft during flight tests. It puts the aircraft through such maneuvers as level acceleration and deceleration, pushover/pullup maneuvers, excess-thrust windup turns, thrust-limited windup turns, level turns, and the rocking-horse maneuver.

The autopilot usually meets and often exceeds the demanding maneuver tolerances: mach number accurate within ±0.01, altitude within ±150 m, angle of attack within ±0.5°, and normal acceleration within ±0.5 × normal gravitation. It increases the quality of maneuvers significantly beyond that attainable through remote manual control by a pilot on the ground. It also increases the quality of maneuvers because it performs maneuvers faster than a pilot could and because it does not have to repeat poorly executed maneuvers.

The aircraft transmits sensor data to the ground (see figure) for use in the cockpit displays on the ground and in the primary-control-system computer. In manual operation, the computer combines the ground pilot's commands with the sensor data. In automatic operation, however, commands generated by the autopilot replace those from the pilot.

The autopilot generates the commands by comparing processed sensor data with those that correspond to the flight-test maneuver selected by the pilot. The autopilot continuously updates the trajectory according to the sensor data it receives. The primary-control-system computer then uses the control law to generate a servoactuator command for the control surfaces and throttle of the aircraft. It sends the servo commands to an uplink encoder for transmission to the aircraft.



The **Autopilot Replaces the Pilot** during automatic maneuvers. The pilot, based on the ground, flies the aircraft to the required altitude, then turns control over to the autopilot.

The autopilot selects various combinations of flight modes according to the maneuver being executed:

- The altitude-hold mode maintains altitude during straight and level flight.
- The angle-of-attack mode provides control of the longitudinal axis during windup turns and pushover/pullup maneuvers.
- The normal-acceleration mode is used in windup turns and the rocking-horse maneuver.
- The wings-level mode controls the lateral axis in both straight and level flight and pushover/pullup maneuvers.
- The turn-control mode controls the lateral axis during any of the turning maneuvers.
- The throttle-control mode is used in all maneuvers except the pushover/pullup with fixed throttle.

The control laws were established by linear analysis and classical design techniques and were expanded by including nonlinear elements. Additional maneuvers can be easily constructed from the basic laws.

This work was done by Eugene L. Duke, Frank P. Jones, and Ralph B. Roncoli of **Ames Research Center**. *Further information may be found in NASA TP-2618 [N88-21153], "Development and Flight Test of an Experimental Maneuver Autopilot for a Highly Maneuverable Aircraft."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
ARC-12102

Final-Approach-Spacing Subsystem for Air Traffic

An automation subsystem gives air-traffic controllers choices of assistance and information.

Ames Research Center, Moffett Field, California

An automation subsystem of computers, computer workstations, communication equipment, and radar helps air-traffic controllers in a terminal radar approach-control (TRACON) facility manage the sequence and spacing of arriving aircraft for both efficiency and safety. Called FAST (for Final Approach Spacing Tool), the subsystem enables controllers to choose among various levels of automation.

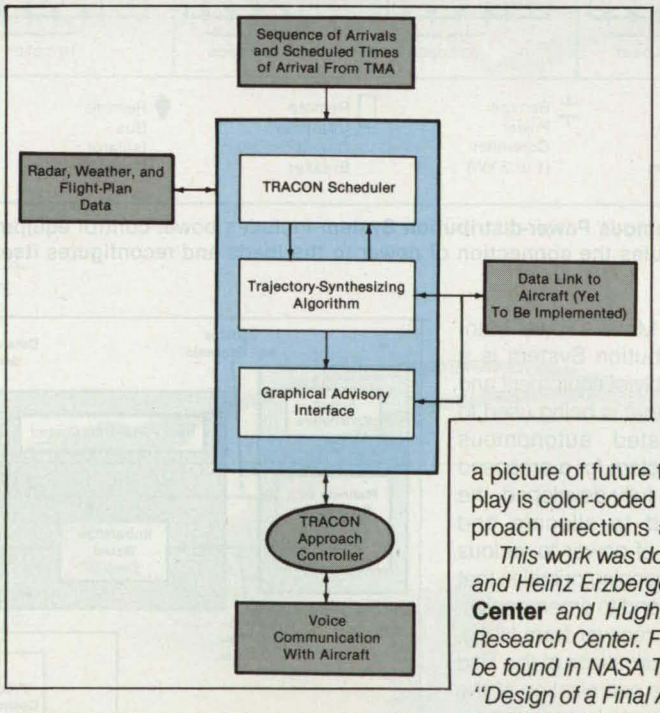
The FAST uses trajectory-synthesizing and scheduling algorithms, mouse interactive input, and graphical interfaces to present controllers with advisory information including predicted errors in scheduled times of arrival and recommended speeds and headings to control such errors. It uses a time line to display current schedule and sequence information for all aircraft in the airspace of the TRACON. As part of an integrated traffic-management system, the FAST exchanges traffic information and communicates with other automation subsystems in the air-route traffic-control center (ARTCC) associated with the TRACON.

The FAST includes the TRACON scheduler, which accepts the scheduled times of arrival generated by the automated Traffic Management Advisor (TMA), another subsystem of the overall traffic-management system (see figure). However, the TRACON scheduler reschedules individual aircraft as necessary to accommodate such special circumstances as large time errors, "pop-ups" (unexpected appearances of aircraft), and missed approaches.

Once a new scheduled time of arrival has been computed, the trajectory-synthesizing algorithm computes a landing path. Today, the controller would give a clearance to the aircraft by voice, but when a data link becomes available, such clearance messages will be sent automatically.

The graphical interface was designed with special concern for air-traffic controllers' preferences. Once a controller has selected a level of automation, advisories appear automatically — close to the aircraft symbols on the display. The controller can increase or decrease the level of automation to take a quick look at advisories in the middle of a traffic rush. Pictures of the proposed landing path are presented well in advance so that the controller can plan ahead and instruct pilots without cluttering the display.

The time-line display gives the controller not only a list of current aircraft but also a picture of future traffic density. The display is color-coded to indicate different approach directions and speeds.



The **FAST** is part of an integrated aircraft-traffic-management system. It accepts data from and provides data to other subsystems to ensure that arrivals are scheduled both efficiently and safely.

This work was done by Thomas J. Davis and Heinz Erzberger of **Ames Research Center** *and Hugh Bergeron of Langley Research Center. Further information may be found in NASA TM-102229 [N90-10841], "Design of a Final Approach Spacing Tool for TRACON Air Traffic Control."*

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ARC-12708

Automated Power-Distribution System

Capabilities include allocation and scheduling according to priorities, and also include recovery from faults.

Marshall Space Flight Center, Alabama

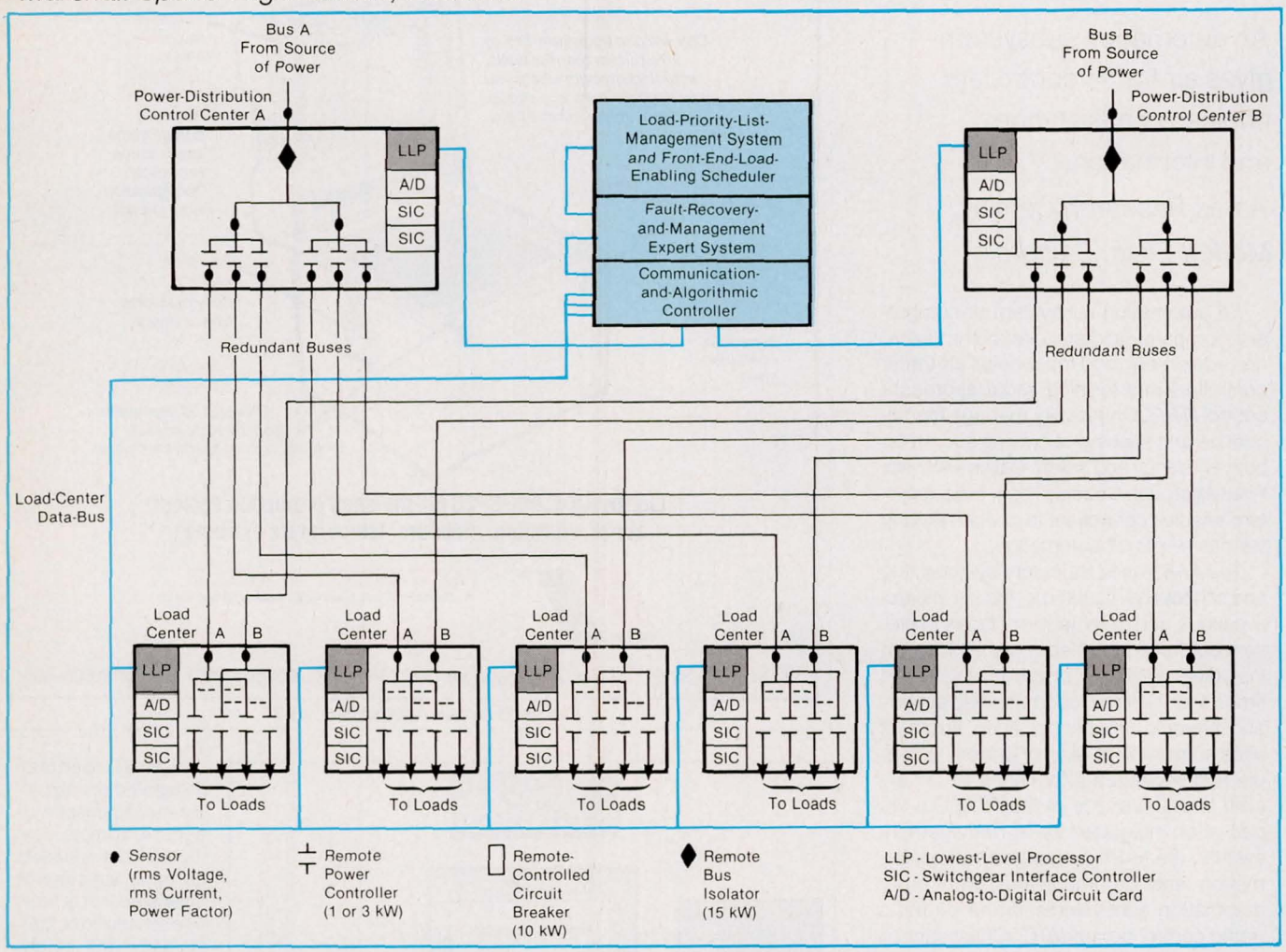

Figure 1. **The Autonomous Power-distribution System** includes power-control equipment and automation equipment. The system automatically schedules the connection of power to the loads and reconfigures itself when it detects a fault.

The Space Station Module Power Management and Distribution System is a "breadboard" assembly of equipment and computer programs that is being used to develop an automated, autonomous power-distribution system for a proposed space station. When fully developed, the system is expected to allocate and schedule the supply of power to various loads according to changing priorities that it determines, to respond to emergencies, and to diagnose and recover from faults. Potential terrestrial applications of this kind of system include the optimization of the consumption of power in homes, power supplies for autonomous land vehicles and vessels, and power supplies for automated industrial processes.

The system was built in two versions: one for a 20-kHz, 208-Vac source and one for a 120-to-150-Vdc source. In each version, power is supplied from the source

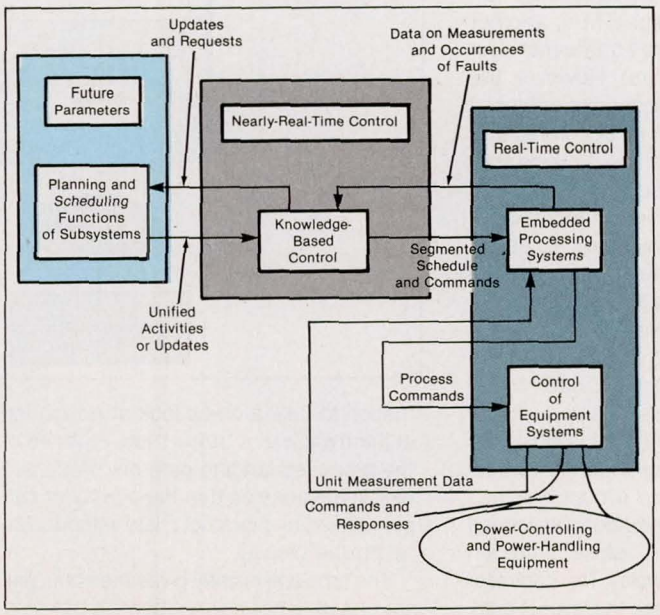

Figure 2. The **Hierarchical Relationships** *among the computer programs that reside in different pieces of equipment provide both rapid response to emergencies and faults and the benefits of artificial intelligence, which performs diagnosis, scheduling, and reconfiguration at a more leisurely pace.*

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Circle Reader Action No. 461

through two power-distribution control units and from these units through redundant buses to six load centers (see Figure 1). Each load center supplies power to the loads connected to it according to the schedule generated by the system. When the system detects a short circuit or other fault in one of the loads, it does not merely turn off power to that load: it reconfigures itself while continuing to operate and reschedules its activities in a manner that takes account of the fault.

From a system-architectural point of view, the system can be classified as consisting of multiple distributed hardware and software agents. The hardware comprises two distinct elements. One element is the power-control equipment through which current flows to the loads. This element includes analog equipment and the digital lowest-level processors in the power-distribution control units and load centers. The other hardware element is the automation equipment, which includes computers and process-oriented circuit cards that do not handle the current being distributed.

The partition and distribution of software functions provide the capability for real-time control that blends artificial-intelligence processing (which is slow) for high-level functions (e.g., diagnosis and scheduling) with deterministic processing (which is fast) for low-level functions (e.g., detecting a short circuit and switching off power pending diagnosis and rescheduling at the high level). The architecture of the software takes advantage of the architecture of the hardware in that the deterministic components of software reside in the distributed processing equipment connected directly to the power-control equipment in the power-distribution control units and load centers. Slower artificial-intelligence application programs reside farther from this power-control equipment, the slowest being the farthest in terms of the hierarchical relationships among the components of software (see Figure 2). This system concept provides a "crisp" command structure close to the power-control equipment and a more refined reasoning structure that takes over when time allows.

This work was done by Barry Ashworth, Joel Riedesel, Chris Myers, William Miller, Ellen F. Jones, Kenneth Freeman, Richard Walsh, Bryan K. Walls, David J. Weeks, and Robert T. Bechtel of Martin Marietta Corp. for **Marshall Space Flight Center**. *For further information, Circle 65 on the TSP Request Card.*
MFS-28504

Two AFC Loops for Low CNR and High Dynamics

Tracking abilities lie between those of a cross-product AFC loop and of a maximum-likelihood estimator.

NASA's Jet Propulsion Laboratory, Pasadena, California

Two alternative digital automatic-frequency-control (AFC) loops have been proposed to acquire (or reacquire) and track the frequency of a received carrier radio signal. The loops are intended for use where the carrier-to-noise ratios (CNR's) may be low and carrier frequency may be characterized by a high Doppler shift and Doppler rate because of high relative speed and acceleration, respectively, between the transmitter and receiver. Either of the proposed AFC loops would be used in place of a phase-locked loop, which cannot operate under such conditions. The new loop concepts integrate ideas from classical spectrum-estimation, digital-phase-locked-loop, and Kalman-Filter theories.

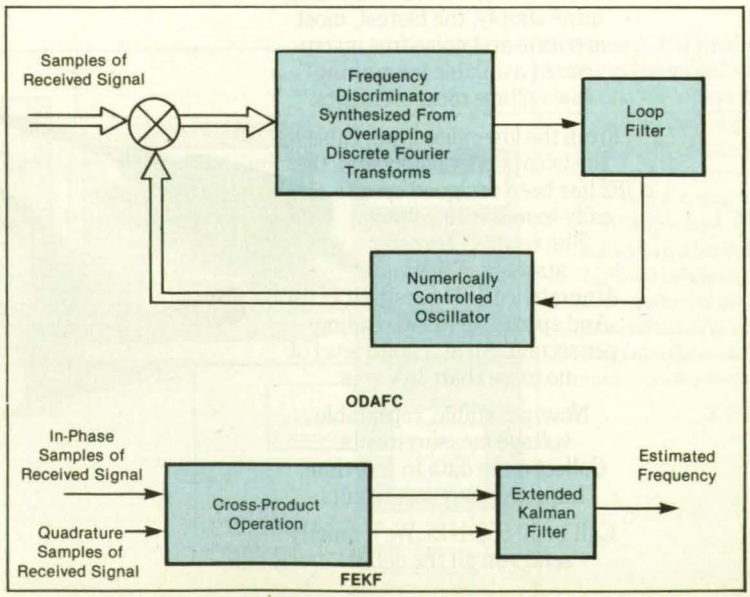
The optimum carrier-frequency-tracking loop (a maximum-likelihood estimator) is impractically complicated and would require an excessive amount of computation. The proposed AFC loops are based on suboptimum frequency-estimation strategies selected to obtain acceptable compromises between the desirability of low operating CNR threshold and good tracking performance on the one hand and the undesirability of complexity and much computation on the other hand. These loops would be generalizations of the cross-product frequency-control loop.

The first frequency-estimation scheme (see figure) is called "overlapping-discrete-Fourier-transform-based automatic frequency control" (ODAFC) loop. In this scheme, running, overlapping discrete Fourier transforms would be used to implement a frequency discriminator. In the absence of noise, the output of this discriminator would be nearly proportional to the error in the estimated frequency for errors up to about one-tenth the sampling frequency.

The second frequency-estimation scheme is called "frequency-estimator extended Kalman filter" (FEKF). In this scheme, the received signal would first be preprocessed in a cross-product operation like that of a cross-product AFC loop to eliminate the phase information. (The reason for this is that it can be inferred from some previous studies that a tracking loop that eliminates the phase information first might be able to operate at a slightly lower minimum signal-to-noise ratio than does one that estimates the phase also.) The preprocessed samples would then be fed to the extended Kalman filter.

Each of the proposed AFC loops offers a distinct advantage. The ODAFC would create a superior discriminator characteristic, whereas the FEKF would provide a superior loop filter. Computer simulations show that these loops can operate at lower carrier-to-noise ratios (albeit with greater root-mean-square frequency errors) than do other popular tracking AFC loops. The performances of these loops were found to lie between those of a typical cross-product AFC loop and of a maximum-likelihood estimator.

This work was done by Sami M. Hinedi and Sergio Aguirre of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 54 on the TSP Request Card.*
NPO-17793



These Proposed Carrier-Frequency-Tracking Loops would operate under low-noise, high-Doppler-rate conditions in which phase-locked loops do not work.

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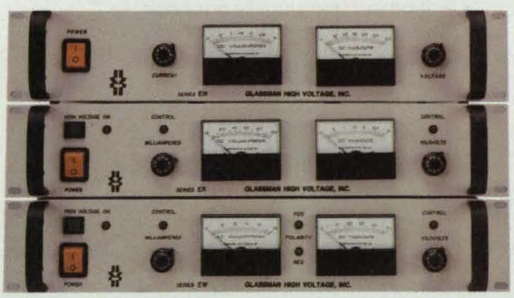

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Circle Reader Action No. 487

Simulation of Static and Moving Acoustical Sources

Sounds in headphones are even changed according to movements of the listener's head.

Ames Research Center, Moffett Field, California

A signal processor generates three-dimensional sound cues for headphones. It provides up to four independent acoustical sources simultaneously and simulates the movements of each source in real time. It can be used to enhance presentations of data in the cockpits of airplanes, in air-traffic-control towers, for training people whose hearing is impaired, for monitoring telerobots in hazardous situations, and for visualizing multidimensional scientific data, among many possible applications.

The processor simulates three-dimensional motion by synthesizing sound waves that are tailored to the specific characteristics of a listener's ears. Its waveforms are thus nearly identical to those that would be produced by free-field sound sources. The synthesis is based on head-related transfer functions—the listener-specific, direction-dependent functions that express the acoustic effects imposed on incoming signals by the outer ears. Head-related transfer functions are measured as finite-impulse responses with small probe microphones placed near the two eardrums of a listener in an anechoic chamber. These measurements are taken with a source of sound at each of 144 different locations at intervals of 15° in azimuth and 18° in elevation. A map of finite-impulse-response location filters is then constructed from the 144 binaural pairs of finite-impulse responses.

The map data are fed to a digital processor, the convolvotron, that convolves the digitized version of an analog signal with location-filter coefficients based on the coordinates of the source of the signal and the position and orientation of the listener's head. This places the signal in the listener's perceptual three-dimensional space. The processor can handle more than 300 million multiplication-and-accumulation operations per second.

The system monitors the position and orientation of the listener's head and uses the resulting data to maintain a fixed apparent position for a static source or an accurate trajectory for a moving source, regardless of how the head moves. Inasmuch as a listener often turns toward a localized source of sound, this adds to the verisimilitude of the simulation.

The processor simulates locations of sources of sound with a resolution greater than that of the measurements on which the finite-impulse response are based by interpolating between measurement positions with linear weighting functions. Studies have shown that listeners cannot distinguish signals interpolated between sources as far apart as 60° in azimuth from those synthesized from measurements.

This work was done by Elizabeth M. Wenzel of **Ames Research Center**, *Scott H. Foster of Crystal River Engineering, and Frederic L. Wightman and Doris J. Kistler of the University of Wisconsin. For further information, Circle 30 on the TSP Request Card.*
ARC-12768

White-Light, Dispersed-Fringe Interferometric Keratometer

A single "snapshot" would suffice to map a cornea.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed keratometer (an optical instrument that measures the shape of the cornea) would be based on a novel scheme that involves the spectral dispersal of white-light interference fringes. While the instrument is intended primarily for use in medical assessments of human corneas, it could also be used to measure the shapes of animal corneas, lenses, and other aspherical or spherical reflective or partly reflective surfaces. A primary advantage of the instrument is that it would operate in a "snapshot" mode: no scanning would be necessary, and it would not be necessary to immobilize the patient's eye. The instrument would be insensitive to vibration, would involve no phase shifting, and would have variable sensitivity.

The bulk of the instrument would be a Twyman–Green interferometer with a source of white light (see Figure 1). The optical train would be achromatized, principally by use of reflective (as opposed to refractive) optics. By use of an area-to-line manifold of optical fibers and a prism or other disperser, the spectrum at each of a number of points in the polychromatic interference image would be spread out on a two-dimensional array of detectors, with wavelength along one axis and position along the other axis (see Figure 2). It has been shown that the autocorrelation function of the spectrum at each such image point should be characteristic of a given interferometric optical-path difference that corresponds to a given height, at that point, of the cornea or other surface under test. Thus, one could generate topographical data on the surface in a single exposure (e.g., a single video frame), without vibration-sensitive scanning or phase shifting.

To obtain the benefit of this "snapshot" approach, it would be necessary to pay a penalty in the form of sparse sampling of the surface under test. This is because the points in the two-dimensional test pupil would not be mapped onto a two-dimensional detector array, but only onto a number of points equal to the number of detectors along one axis of the array (the other axis being reserved for dispersion of the spectrum). One could trade-off the number of sampling points, resolution or sensitivity (uncertainty in the optical-path difference), and dynamic range (maximum optical-path difference) against each other. For example, a preliminary analysis shows that the topography of a cornea could be measured to a resolution of 20 μm on an array of 74×74 sampling points, using a 256×256-element charge-coupled device as the detector array.

This work was done by Eric B. Hochberg and Edmund C. Baroth of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 87 on the TSP Request Card.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

Edward Ansell
Director of Patents and Licensing
Mail Stop 305-6
California Institute of Technology
1201 East California Boulevard
Pasadena, CA 91125

Refer to NPO-17955, volume and number of this NASA Tech Briefs *issue, and the page number.*

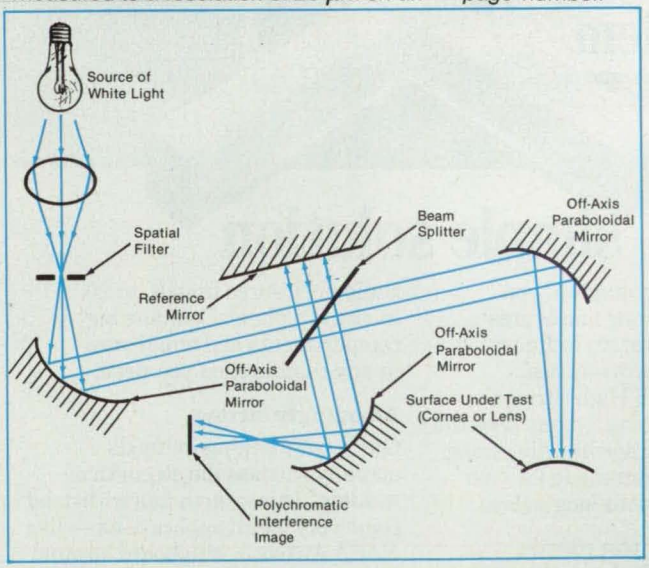
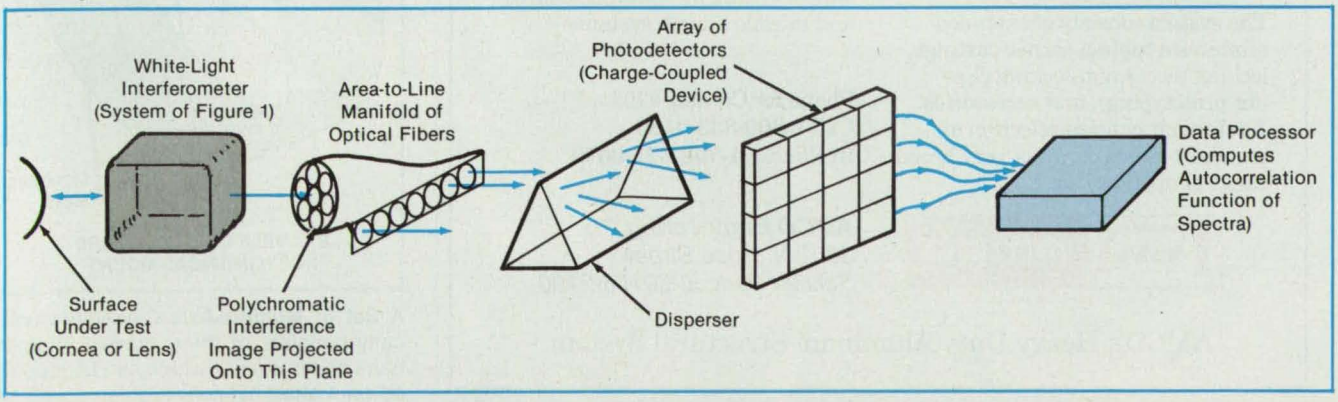


Figure 1. A **Twyman-Green Interferometer** illuminated by white light would generate a polychromatic interference image of the surface under test.

Figure 2. **Spectra at a Number of Sampling Points** in the polychromatic image would be measured, and the autocorrelation function of the spectrum of each point would indicate the height of the surface under test at that point.



Multiple-Axis Crosshairs

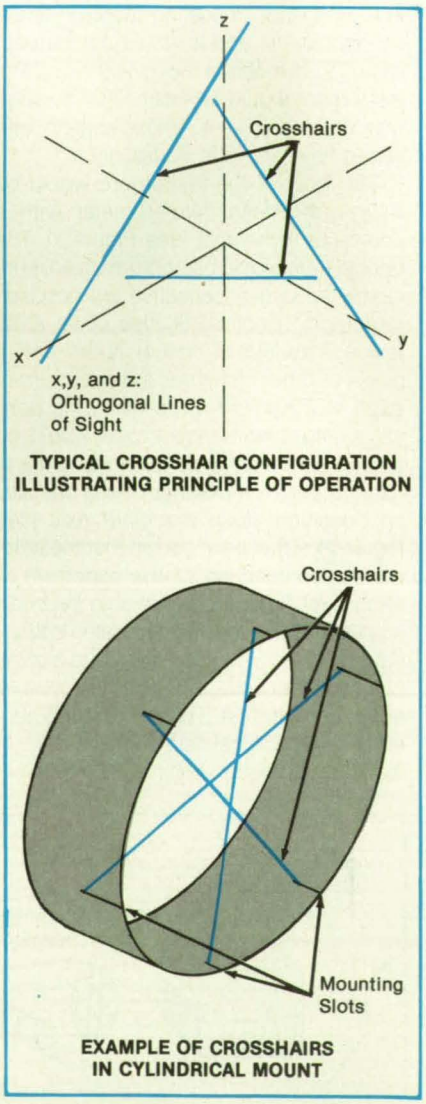
Three skewed lines provide alignment when viewed along each of three mutually orthogonal axes.

Ames Research Center, Moffett Field, California

A multiple-axis crosshair device provides alignment when viewed along any of three mutually orthogonal axes. Because the device can be viewed in either direction along a given axis, it provides for viewing from any of six directions perpendicular to the faces of a cube. Unlike in many previous devices, the location of the common or target point can be "empty;" that is, no part of any crosshair has to pass through the target point.

In one version of the multiple-axis crosshair device (see left side of figure), a straight wire placed near (but not at) the origin of the axes in the *yz* plane, and at an angle of 45° to both the *y* and *z* axes serves as a crosshair in the *z* direction when viewed in either direction along the *y* axis or as a crosshair in the *y* direction when viewed along the *z* axis, thus locating the *yz* plane. Similarly, a wire placed analogously in the *xz* plane serves as a crosshair in the *x* and *z* directions and locates the *xz* plane, while a wire placed analogously in the *xy* plane serves as a crosshair in the *x* and *y* directions and locates the *xy* plane. Because there is no requirement that any of the three wires pass through the origin (the target point) or any other point, the mounting of the three wires is not complicated by mechanical interference among them.

In addition to being simpler and more compact than previous sets of crosshairs with similar capabilities have been, this device is more accurate and reliable because the same wire defines the same plane from two different directions. More-



A **Set of Multiple-Axis Crosshairs** typically consists of three skewed straight hairs or wires (left), which can be mounted on a short cylinder (right).

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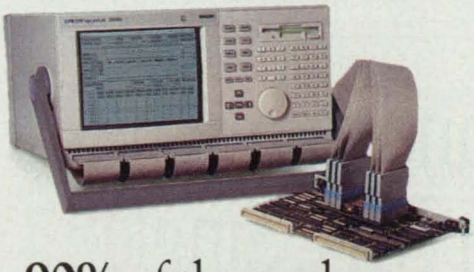

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over, because the target point can be "empty," a pentaprism can be placed there to serve as a convenient means of establishing orthogonal lines of sight through the target point. In one form, in which the three wires are all parallel to a common plane, a mount for the three wires can be made from a short cylinder with six short slots equally spaced around one end (see right side of figure); no part of the mount obstructs the six possible lines of sight.

This work was done by Chris Barns of **Ames Research Center** *and William Gunter, Jr., of Photon Applications. For further information, Circle 25 on the TSP Request Card.*

This invention has been patented by NASA (U.S. Patent No. 4,957,357). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Ames Research Center [see page 16]. Refer to ARC-11886.

Electrostatic Particle-in-Cell Code for Hypercube Computer

A regular partition of the field grid serves well in a two-dimensional problem.

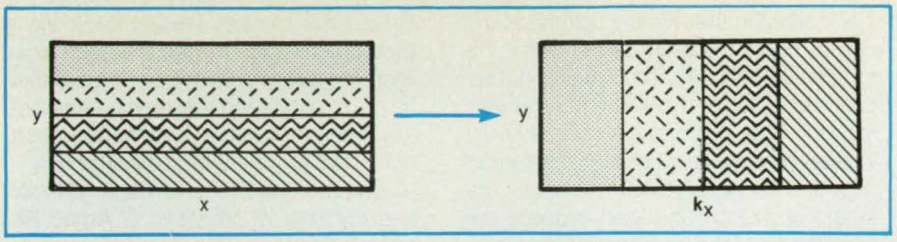
NASA's Jet Propulsion Laboratory, Pasadena, California

A code that simulates two-dimensional motions of plasma particles in a self-consistent electrostatic field and an externally applied magnetic field has been developed for execution on the Mark IIIfp hypercube computer. The code is of the particle-in-cell type, in which particles are deemed to move among the cells of the computational grid. This code is based on a generalization of a one-dimensional particle-in-cell algorithm that is applicable to many different parallel computing architectures. As such, it is an intermediate product of a continuing effort to speed particle-in-cell computations by taking advantage of distributed-memory parallel computers like those of the hypercube class.

A plasma particle-in-cell code propagates, in time, the trajectories of thousands to millions of charged particles. At each time step, two major computations are performed: first, the position and velocity of each particle are updated by integration of Newton's equations of motion in the electric and magnetic fields (this update is called the "particle push"), and the charges at their updated positions are interpolated onto the grid used to compute the fields. Next, the updated distribution of charges is used to update the electrostatic field. Because the particle push requires the majority of the computation time, it is necessary to assign an approximately equal number of particles to each of the processors to obtain the maximum advantage from parallel computing. The grid used to compute the fields must also be distributed among the processors, not necessarily in the same manner as that of the particle push.

In this specific two-dimensional case, the field grid is decomposed in a regular manner, assigning each part to a processor. This makes it necessary to transfer a particle from one processor to another when its updated position is found to be in the portion of the field grid handled by the other processor. In principle, this could give rise to large imbalances among the numbers of particles (and, therefore, the computational loads assigned to the processors). In practice, for the class of problems for which this regular decomposition is appropriate, large imbalances do not occur.

The main loop of the computer code proceeds as follows. First, the distribution of charges in real space is interpolated onto the field grid, then transformed into **k**



In this **Field-Grid Decomposition** for the two-dimensional fast Fourier transform (FFT), a strip of the field grid is assigned to each processor initially so that it can do one-dimensional FFT's in x for its subset of the y dimension. The results are then redistributed so that each processor is responsible for a strip oriented along y. One-dimensional FFT's in y can then be performed in each processor for its subset of $\mathbf{k}_x$.

space by a two-dimensional fast Fourier transform (see figure) algorithm. Poisson's equation is solved in **k** space, and the x and y components of the electric field are computed from its solution. Then the two components of the electric field are transformed back into real space.

The interpolation of the fields from the grid for all of the particles requires guard rows on both sides of the grid, because particles at a grid boundary require field information from the processor responsible for the neighboring part of the grid. This guard-row information is exchanged between processor neighbors before the push phase begins. The processors are mapped into a logical ring so that only communication between nearest neighbors is required for the exchanges. Because some particle charge is interpolated onto the guard rows, these rows must be combined with their counterparts in adjacent processors before the deposition of charge is complete. This, too, requires only nearest-neighbor communication.

The code has been applied to a problem of 16,128 particles on a 32×128 field grid. The computational efficiency for the particle push was found to remain close to 100 percent as the number of processors was increased from 1 to 32. However, the computational efficiency for the solution of the field equations and, therefore, the overall computational efficiency decreased as the number of processors was increased. This decrease is attributed to an increase in communication among processors necessary to solve the field equations.

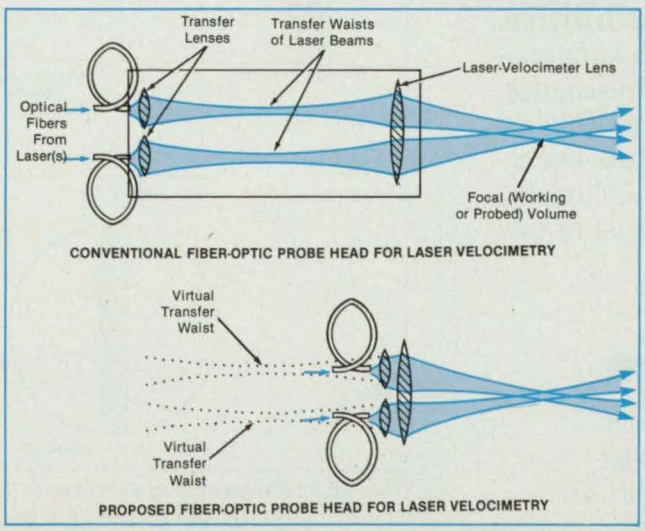
This work was done by Robert D. Ferraro and Paulett C. Liewer of Caltech and Viktor K. Decyk of UCLA for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 77 on the TSP Request Card. NPO-18229*

Fiber-Optic Probe for Laser Velocimetry

The size and weight of optics would be reduced considerably.

Ames Research Center, Moffett Field, California

A proposed fiber-optic probe in a laser velocimeter would be smaller (and, therefore, lighter in weight and more maneuverable) than previous such probes have been. Typically, an optical-fiber probe is used in the transmitting optics of a laser velocimeter to enable the laser-velocimeter lens to be moved to scan the probing beams across the test volume while the laser(s) and associated optical components remain fixed. This reduces the number and weight of optical components that have to be moved. However, the positions and orientations of the lenses and the out-



The **Proposed Fiber Optic Probe Head** would be more compact and, therefore, lighter in weight and more maneuverable.

put ends of the fibers in the probe head must be maintained precisely, and the distance between the ends of the fibers and the laser-velocimeter lens can be large — of the order of meters. Thus, even though a conventional fiber-optic probe head does not have to carry the laser(s), it must nevertheless be made relatively large and heavy to maintain the necessary optical alignments.

The optical configuration of a fiber-optic probe head for laser velocimetry is dictated by the required working distance (approximately the focal length of the laser velocimeter lens) and the need to make the waists of the intersecting laser beams have the proper diameter and location. Usually, one needs waists as narrow as possible, located in the working volume at the intersection of the beams. As shown in the top part of the figure, the conventional optical configuration requires a transfer lens for each laser beam and a transfer waist located in each beam between the transfer lens and the laser-velocimeter lens. The length of this configuration exceeds the focal length of the laser-velocimeter lens.

The proposed configuration, illustrated in the bottom part of the figure, is the product of calculations and experiments that show that the beams do not have to be focused to real waists before they pass through the laser-velocimeter lens: virtual waists can serve the same purpose. By appropriate repositioning of the transfer lenses, one could obtain virtual waists behind the transfer lenses, back along their optical axes toward the sources of light. The laser-velocimeter lens could then be brought close to the transfer lenses to focus on the virtual waists, thereby shortening the probe head considerably.

This work was done by Dana H. Lynch and Kenneth W. McAlister of **Ames Research Center** *and William D. Gunter, Jr., of Photon Applications. For further information, Circle 26 on the TSP Request Card.*

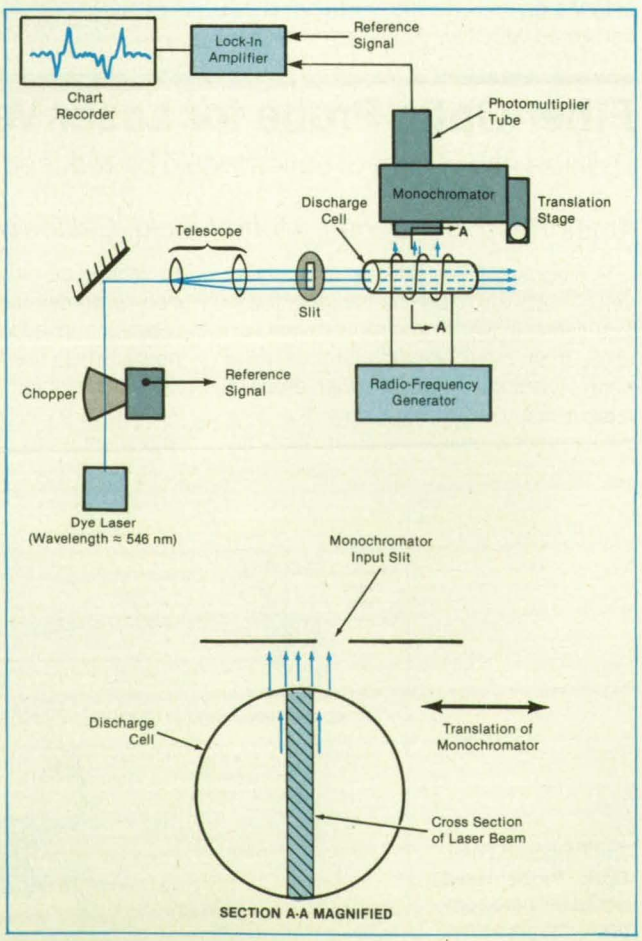
This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Ames Research Center *[see page 16].* *Refer to ARC-11889.*

Laser-Induced-Emission Spectroscopy in Hg/Ar Discharge

This technique was used to determine the concentration and influence of metastable Hg ions.

NASA's Jet Propulsion Laboratory, Pasadena, California

Laser-induced-emission (LIE) spectroscopy (see figure) has been used to probe a low-pressure mercury/argon discharge to determine the influence of mercury atoms in the metastable 6^3P_2 state on the emission of light from the discharge. Whereas laser-induced fluorescence and laser-induced stimulated emission rely on the observation of light emitted from an upper energy level that is optically connected by the laser to a lower level, LIE spectroscopy enables one to examine the responses of all lines in the spectrum of the discharge to the changes in the population of a state that are caused by the laser optical field. Thus, one can use LIE to study all excitation processes affected by the metastable population, including possible effects on the excitation of atoms, ions, and the buffer gas. The LIE spectroscopic technique, which could be applied to the emissions of other plasmas, provides data that can be used to make more-accurate models of such emissions, which are exploited by the lighting and laser industries and by laboratories studying discharges.



This **LIE Spectroscopic Apparatus** was used to study the influence of the 6^3P_2 metastable level of Hg in a Hg/Ar discharge.

The figure illustrates the LIE apparatus that was used to characterize the Hg/Ar discharge. A continuous-wave dye laser generated light at a wavelength of 546.1 nm (corresponding to the transition between the 6^3P_2 and 7^3S_1 levels of Hg). The laser light was introduced into a cylindrical quartz discharge cell that had a diameter of 2.5 cm and a length of 10 cm. The cell contained a few milligrams of mercury in addition to argon at a pressure of 800 mtorr ($\approx$100 Pa). The discharge was energized by coupling from a radio-frequency oscillator. The laser beam was passed through a rectangular aperture to produce a ribbon of light, which was then directed into the discharge cell along its axis. The discharge was monitored by observing the optogalvanic signal.

Light emitted by the discharge was monitored by a monochromator with rectangular slits parallel to the axis of the cell and the ribbon of laser light. The monochromator was mounted on a micrometer-driven translation stage for measuring emissions at various positions relative to the midplane of the ribbon of laser light. The output of a photomultiplier tube located at the output port of the monochromator was fed to the input terminal of a lock-in amplifier. The lock-in reference signal was provided by a device that chopped the laser beam on the way to the discharge cell. The output of the lock-in amplifier was fed to a chart recorder, which recorded the spectral signals.

Measurements of the intensities of the emission spectral lines led to the following conclusions:

- The dominant mechanism for the excitation of the higher energy levels of mercury atoms in the discharge is the electron-impact excitation from the $^3P_2$ level.
- The depopulation of this metastable level is responsible for an observed increase in the electron temperature when the laser irradiates the discharge. This conclusion implies that more-efficient lamps for the mercury ion standard may be designed through approaches in which the population of the $^3P_2$ level is quenched. This may be accomplished, for example, by the addition of a small amount of nitrogen or another gas that could quench the metastable level by collision.
- The $^3P_2$ metastable level of the mercury atom does not play a significant role in the excitation of the $^2P_{1/2}$ level of the mercury ion.

LIE spectroscopy may also be useful in making quantitative measurements of the relative rates and cross sections of the direct and two-step collisional processes that involve a metastable level. This could be accomplished if the magnitude of the metastable population in the field of view of the monochromator could be determined.

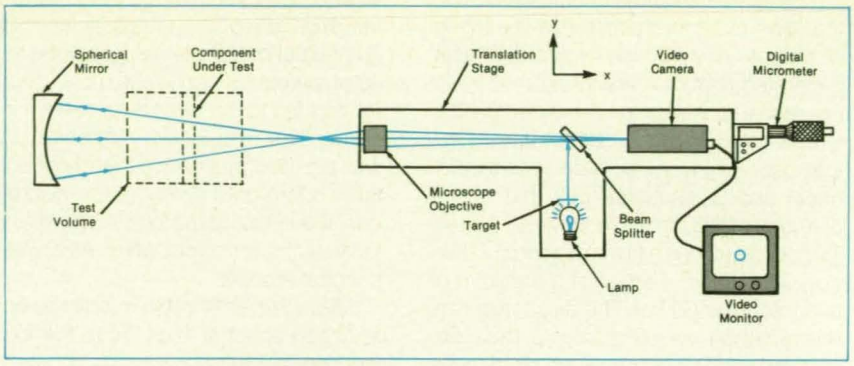
This work was done by Lutfollah Maleki, Barry J. Blasenheim, and Gary R. Janik of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 75 on the TSP Request Card.*
NPO-18203

Instrument Measures Shift in Focus

Optical components can be tested at wavelengths from ultraviolet to infrared.

NASA's Jet Propulsion Laboratory, Pasadena, California

An instrument measures the distance along which the focal point of a converging beam of light is shifted by the introduction of a nominally plane parallel optical component into the beam. The instrument is intended primarily for measuring focus



The **Focus-Shift-Measuring Instrument** is easy to use. It can be operated in a lighted room, without having to make delicate adjustments while peering through a microscope.

shifts produced by windows and filters at wavelengths from 120 to 1,100 nm. It is portable, compact, and relatively inexpensive for its degree of precision.

In the instrument (see figure), an illuminated target is mounted on a precise two-dimensional translation stage along with a reflective microscope objective, a beam splitter, and a charge-coupled-device video camera. The target can be a pinhole, slit, bar pattern, or other pattern suitable for the visual detection of focus or the lack thereof. The microscope objective forms an image of the target at the center of curvature of a spherical mirror.

The spherical mirror reimages the target at its center of curvature. The beam reflected by the spherical mirror serves as the convergent testing beam and has a cone angle large enough to provide the required accuracy in measuring the shift in focus. The microscope objective refocuses the reimaged target from the center of curvature of the spherical mirror onto the focal plane of the video camera.

The translation stage is equipped with a digital micrometer to facilitate measurements of focus shifts. The instrument is brought into focus by adjusting the digital micrometer while observing the image on the video monitor connected to the video camera. This focus adjustment is performed both without and with the optical component under test, and the difference between the micrometer readings in the two cases is recorded. The microscope objective increases the sensitivity of the instrument in that the apparent focus shift is multiplied by the square of the magnification. Thus, the focus shift produced by the component under test equals the difference between the micrometer readings divided by the square of the magnification. In this way, the instrument can measure focus shifts with a repeatability of 0.001 in. (25.4 μm).

The use of all reflective optics eliminates chromatic errors and helps make it possible to operate over the broad wavelength range. To make the video camera sensitive to wavelengths below 400 nm, its cover windows are removed and the charge-coupled device is covered by a material that fluoresces visibly under ultraviolet light. In addition to making the image visible when testing with ultraviolet light, the video camera reduces the technician's strain by making it unnecessary to peer through a microscope. Furthermore, because the instrument is enclosed, it can be operated in a lighted room.

This work was done by Lawrence J. Steimle of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 74 on the TSP Request Card.*
NPO-18249

Materials

Polymeric Electrolyte Containing 12-Crown-4 Ether

Ionic conductivity and charge-transfer efficiency are enhanced.

NASA's Jet Propulsion Laboratory, Pasadena, California

Experiments show that the incorporation of 12-crown-4 ether into solid electrolytes based on polyethylene oxide can enhance their electrochemical properties. More specifically, 12-crown-4 ether may increase the Faradaic efficiency for Li^+ ions in low-power secondary Li cells and thus may enable the operation of these cells at lower temperatures with higher efficiencies.

The conductivity-enhancing effect of 12-crown-4 ether was investigated by measuring the conductivities of thin films of polyethylene oxide/CF_3SO_3Li (5:1 mole ratio of polyethylene oxide to CF_3SO_3Li) cast from solution without and with various concentrations of 12-crown-4 ether. The results of dc electrochemical measurements of ionic conductivity (see Figure 1) and of plating/stripping of Li show that the bulk ionic conductivity of the polymer incorporating 12-crown-4 ether exceeds that of the polymer. Similarly, measurements of the complex impedances at various frequencies (see Figure 2) show that the charge-transfer resistance is smaller for the samples incorporating 12-crown-4 ether.

This work was done by Ganesa Nagasubramanian and Salvador DiStefano of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 162 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 16]. Refer to NPO-17922.

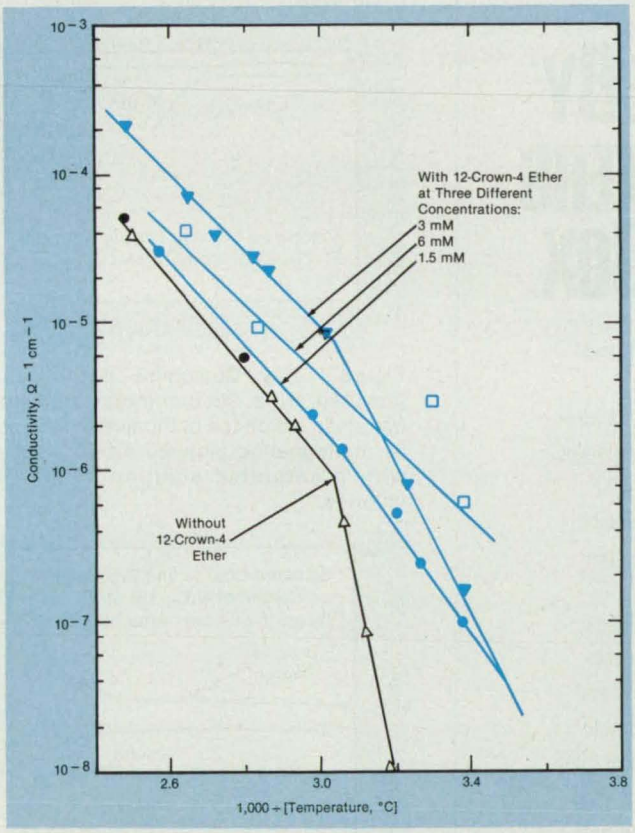


Figure 1. The **dc Ionic Conductivities** of films of (polyethylene oxide)$_5CF_3SO_3Li$ containing 12-crown-4 ether at various concentrations were measured over a range of temperatures.

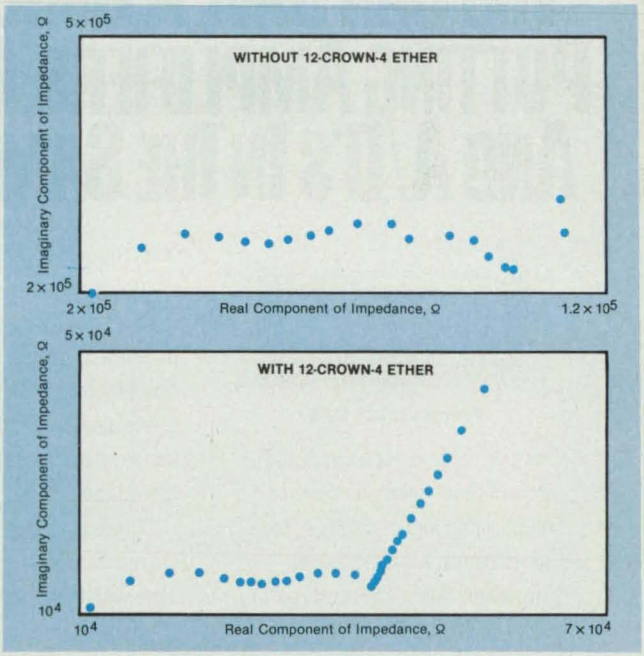


Figure 2. The **Complex Impedances** of two (polyethylene oxide)$_5CF_3SO_3Li$ films, one of which contained 12-crown-4 ether at a concentration of 12 m*M*, were measured at frequencies from 0.1 Hz to 100 kHz.

Making Positive Electrodes for Sodium/Metal Chloride Cells

The electrodes have high coulombic yields and retain them in charge/discharge cycling.

NASA's Jet Propulsion Laboratory, Pasadena, California

Sintered nickel plaques have been impregnated with nickel chloride to form cathodes of $Na/\beta\text{-}Al_2O_3/NaAlCl_4/NiCl_2$ voltaic cells. The resulting cathodes exhibited high coulombic yields at high current densities and suffered very little loss in capacity on charge/discharge cycling. Cells made with these or similar electrodes in which transition-metal chlorides are im-

pregnated in sintered matrices could be used in spacecraft, electric land vehicles, and other applications in which high-energy-density power systems are required.

High-temperature rechargeable sodium batteries in which the cathodes contain metal chlorides offer energy densities comparable to those of sodium/sulfur batteries but are safer and are less susceptible to corrosion because they operate at lower temperatures. In addition, certain failure modes encountered in sodium/sulfur batteries — for example, the degradation of solid electrolytes in polysulfide melts — are not observed in the sodium/metal chloride batteries.

Previously, cathodes for sodium/metal chloride cells have been made by chlorination of porous metal bodies that had been made by sintering metal powder under reduced atmospheres, impregnation of the porous bodies with saturated solutions of sodium chloride followed by assembly in the state of discharge, sintering slurries of metal powder and sodium chloride brine, and sintering dry powders of metal and sodium chloride. In the latter two methods, the chlorination of the electrodes at structurally weak spots, both during the initial formation processes and subsequently, reduces the cycle lives of the electrodes.

In the new method of fabrication, sintered nickel plaque of the type used in Ni/Cd batteries is impregnated with nickel chloride from a saturated nickel chloride solution. In principle, vacuum impregnation could be used to achieve higher loadings of the active material into the plaque. Also, the nickel plaque could be preoxidized or otherwise pretreated as in the fabrication of Ni/Cd batteries.

To demonstrate the feasibility of the new method of fabrication, nickel chloride was chemically impregnated in a plaque to a loading of 4 mAh/cm^2. The impregnated electrode was dried overnight at a temperature of 150 °C, then tested in charge/discharge cycles. The electrode exhibited high coulombic yields (>95 percent on the basis of the amount of $NiCl_2$ impregnated) at high current densities (up to 8 mA/cm^2) (see Figure 1).

The electrode lost very little capacity in charge/discharge cycling (see Figure 2). This implies that the degree of integrity of the electrode is high. The result is attributed to the nonchlorination of the plaque during fabrication: only the active material contained in the plaque is oxidized. Electrodes of Ni/Cd cells fabricated similarly have previously been shown to have long cycle lives.

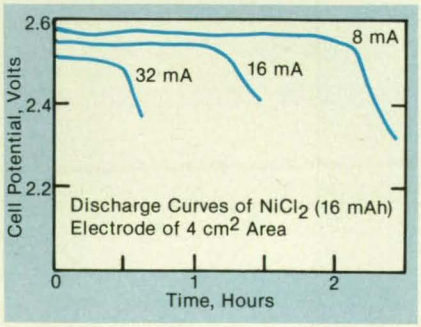


Figure 1. High Coulombic Yields were provided by a sodium/metal chloride battery in which the cathode was formed by impregnating sintered nickel plaque with a saturated solution of nickel chloride.

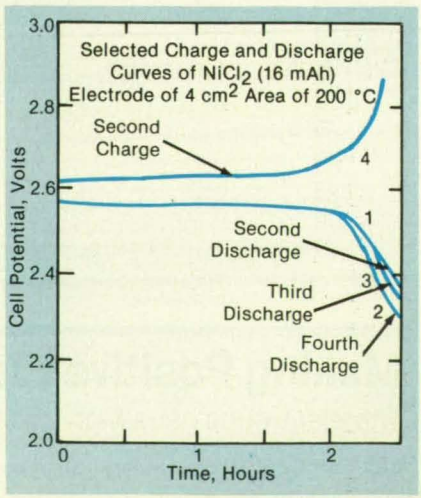


Figure 2. Charge/Discharge Cycling of the nickel chloride electrode resulted in very little loss of capacity.

rtian Times

MONDAY, JULY 21, 2121

Weather

Alpa Patera: **Today**, cold and clear followed by red dust storms. High 10°C. **Tonight**, clear. Low −29°C. **Tomorrow**, chance of meteor showers. High near 20°C. Details, page B12.

$19.95

THE EAGLE I CHRISTENED FOR LAUNCH

A huge crowd gathered to witness the historic ceremony.

By JON LEE

KENNEDY SPACE CENTER, FL (APR)—The Eagle I, a deep space exploration vehicle, was christened today in a ceremony that dates back over 4,000 years. Appropriate for a ship that's to sail the vast oceans of space, and yet an interesting anachronism for a vehicle so technically advanced.

Making History

"This ship is packed with the latest science has to offer," said Chris Levan, Project Manager on the Eagle I. "But if it weren't for Amoco Performance Products, the Eagle I wouldn't even be here."

Amoco was involved in this challenging and complicated project since its beginning. As the only producer of ultra-high modulus pitch-based carbon fibers in the United States at that time, Amoco's participation was crucial.

For example, "all the support struts in the Eagle I are made from THORNEL® P-120 pitch-based carbon fiber," explained Levan. "No other material offered us the combination of high modulus, high thermal conductivity and strength. We were able to reduce the weight of the Eagle I by using P-100 and P-120. Plus, the negative CTE of the fiber allowed us to design zero CTE structures. Dimensional stability is very important to us."

The Eagle I bristles with antenna booms, reflectors and sensors—all made with pitch-based carbon fibers. "The ship is loaded with sophisticated technology and electronics of all kinds," said Levan. "The unsurpassed thermal conductivity of THORNEL® pitch-based carbon fiber makes it an ideal material for electronic enclosures and radiator panels.

"Amoco had fibers readily available from inventory. Their responsiveness kept our program right on schedule," Levan continued.

Pride and Excitement

Positioned on the platform and draped with red, white and blue bunting, the Eagle I glistened in the sunshine as last minute preparations were made.

"It's the blessing of the ship, and a celebration for the thousands of people who worked on her. It takes so many of us to build this thing," said David Maas, who worked on the navigation systems. "It feels great when you can stand back and see how good she looks."

Champagne, Cheers and Sirens

The crowd cheered and waved flags when the ship was christened with the traditional bottle of champagne. When the bottle broke, thousands of balloons were released, the ship's sirens sounded and a squadron from the elite Rocket Corps screamed past overhead.

And so a new chapter in space exploration begins.

Mars to be the site of the LVIII Games

After protracted negotiation and intense lobbying effort, Mars has been designated as location of the next Interplanetary Games. Tharsis [illegible] named as the site because [illegible] is already a huge Sports [illegible] there that thoughtfully incl[illegible] ample parking.

Cont. on Page 14A

This work was done by Ratnakumar V. Bugga, Salvador Di Stefano, and C. Perry Bankston of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 158 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 16]. Refer to NPO-17809

NiF_2 Cathodes for Rechargeable Na Batteries

Energy densities are higher than with metal chlorides.

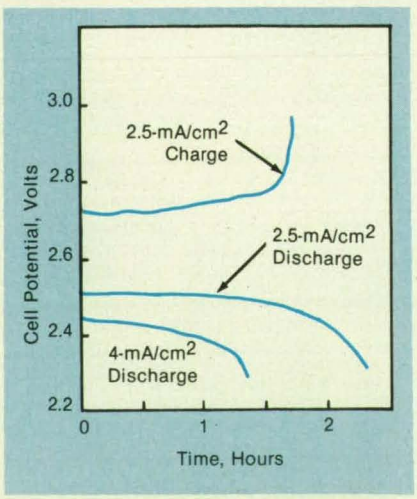
NASA's Jet Propulsion Laboratory, Pasadena, California

The use of NiF_2 cathodes in place of $NiCl_2$ cathodes in medium-to-high-temperature rechargeable sodium batteries increases energy and power densities by 25 to 30 percent without detracting from the potential advantage of safety that this type of sodium battery offers over sodium batteries that have sulfur cathodes. High-energy-density sodium batteries with metal fluoride cathodes could be used in electric vehicles and for leveling loads on powerlines.

Cathodes made of transition-metal chlorides ($FeCl_2$ and $NiCl_2$) have been used as alternatives to sulfur cathodes in rechargeable sodium batteries that are now approaching commercialization. These metal chlorides are typically insoluble in the molten-$NaAlCl_4$ catholytes of these cells. Apart from several potential safety and operational advantages, these systems have theoretical energy densities almost comparable to those of Na/S batteries. However, the practical energy and power densities attainable in these batteries are slightly lower than those of Na/S batteries. This fact has stimulated modifications to enhance the practically attainable energy and power densities.

The use of nickel fluoride in place of nickel chloride would reduce the weight of an energy-equivalent cathode by 25 percent. Assuming that the electrochemical potential is the same as for $NiCl_2$ (it could be higher), the theoretical energy density of NiF_2 is about 1,436 Wh/kg — 34 percent greater than the energy density of $NiCl_2$, which is 1,070 Wh/kg.

In an experiment, nickel fluoride was impregnated from a concentrated aqueous solution into a sintered nickel matrix of the type used as plaques in Ni/Cd batteries. The impregnated matrix was then dried. On the basis of the gain in weight, the amount of NiF_2 in the electrode thus fabricated corresponded to about 48 mAh. The NiF_2 electrode was then tested in a laboratory cell, the configuration of which was Na(molten)/β''–Al_2O_3/$NaAlCl_4$(molten)/NiF_2(solid); this configuration is sim-



These **Charge/Discharge Curves** were obtained from measurements on a sodium cell with a 48-mAh NiF_2 cathode at a temperature of 230 °C.

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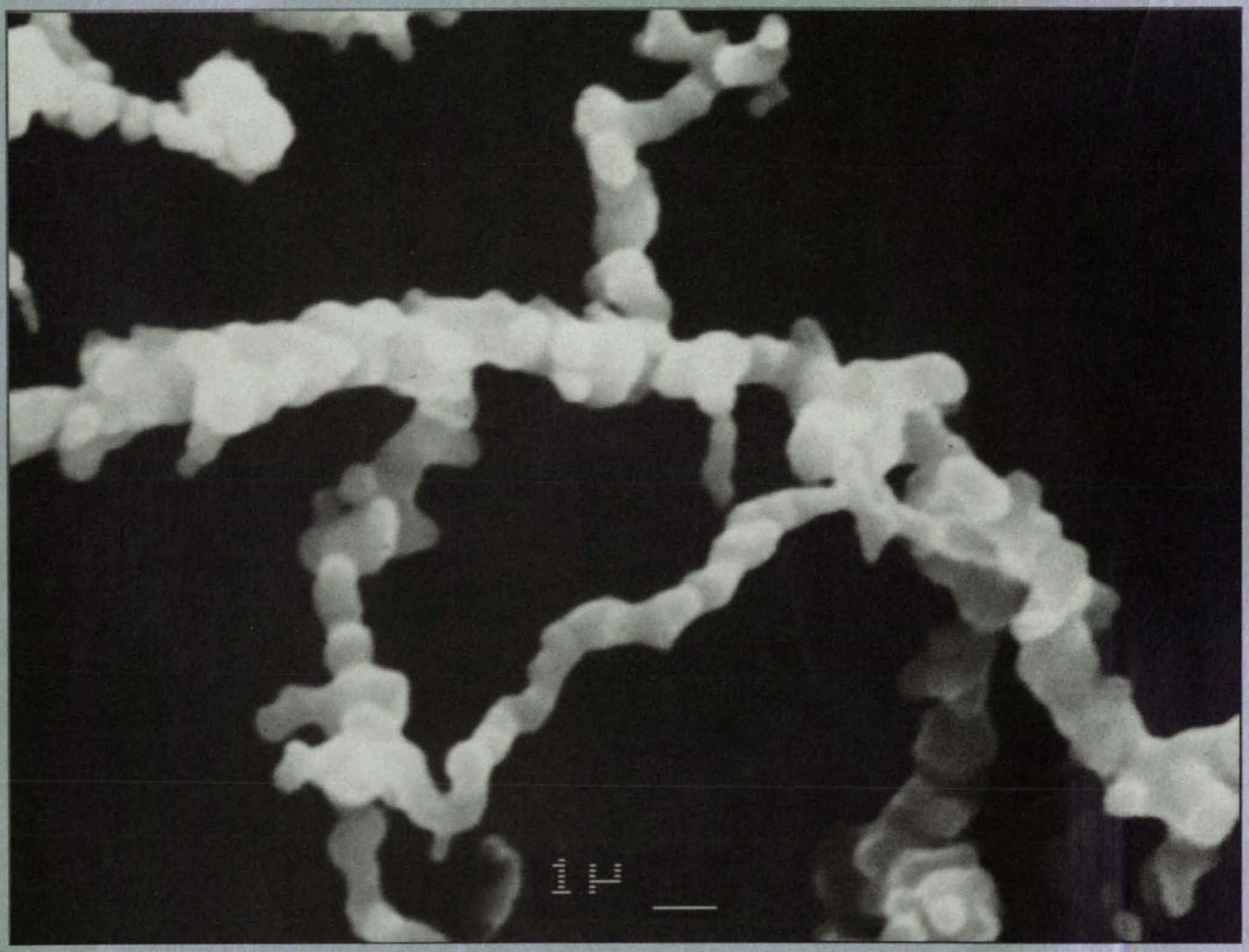

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ilar to that of a sodium/metal chloride cell.

The cell was tested at an operating temperature of about 230 °C. It exhibited charge/discharge curves that resemble those of an $Na/NiCl_2$ cell in that they are relatively flat, and the voltages are about the same (see figure). However, the electrochemical equivalent of the cathode of this cell (0.55 Ah/g) was greater than that of a representative $Na/NiCl_2$ cell (0.41 Ah/g). The coulombic yields in discharge exceeded 90 percent at current densities of 2 to 4 mA/cm^2. The cell exhibited a high degree of reversibility in charge/discharge cycling.

This work was done by Ratnakumar V. Bugga, Salvador Di Stefano, and Gerald Halpert of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 160 on the TSP Request Card. NPO-18119*

Glass-Derived Superconductive Ceramic

A phase of high critical temperature crystallizes from $Bi_{1.5}Pb_{0.5}Sr_2Ca_2Cu_3O_x$ glass during annealing.

Lewis Research Center, Cleveland, Ohio

A critical superconducting-transition temperature (T_c) of 107.2 K, the highest yet observed in a glass-derived superconductor, was observed in a specimen made by annealing a glass of composition $Bi_{1.5}Pb_{0.5}Sr_2Ca_2Cu_3O_x$ for 243 h at 840 °C. Prior to this discovery, it was known that in the Bi/Sr/Ca/Cu/O system, the optimum annealing temperature for the formation of the high-T_c phase is 870 °C. It was also known that when PbO is added, the optimum annealing temperature decreases to 840 °C. PbO had also been found to lower the melting temperature and viscosity of the glass, possibly by acting as a fluxing agent. Alternatively, it had been suggested that the partial substitution of lead into the bismuth oxide planes of a crystalline phase that has a T_c of 110 K stabilizes this phase and facilitates the formation of it.

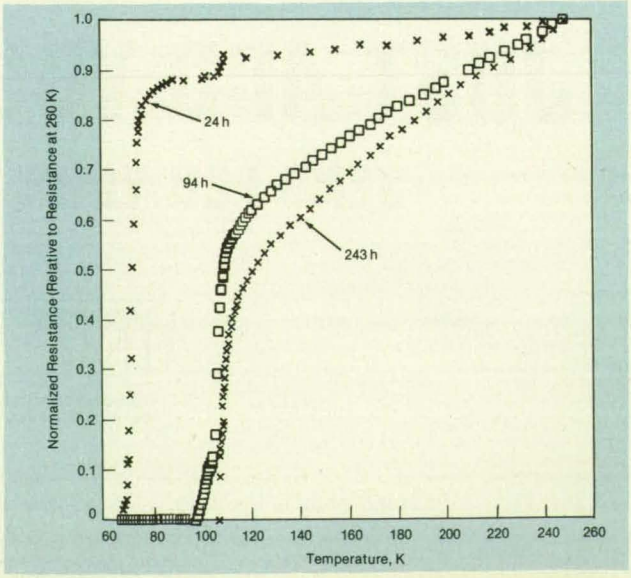
To prepare the glass, appropriate amounts of Bi_2O_3, PbO_2, $SrCO_3$, CaO, and CuO to obtain the nominal composition $Bi_{1.5}Pb_{0.5}Sr_2Ca_2Cu_3O_x$ were mixed in acetone to form a slurry, then thoroughly ground with a mortar and pestle. The mixture was calcined overnight in a platinum crucible in air at approximately 795 °C, then cooled and reground. The resulting gray powder was heated in a covered platinum crucible at about 1,025 °C for approximately 0.5 h. The melt was then quenched between two copper plates, forming opaque black glass sheets about 1 mm thick.

These sheet specimens were characterized by various techniques. Powder x-ray diffraction using Kα radiation showed a broad halo pattern indicative of an amorphous material. However, some low-intensity peaks that could be matched with CaO were also present. Chemical compositions were determined by atomic absorption. Differential thermal analysis (DTA) was performed in air at a heating rate of 10 °C/min. The specimens were found to have a glass-transition temperature of 383 °C, a crystallization temperature of about 446 °C, and a melting temperature of 855 °C.

One specimen was not annealed. The others were annealed in air at temperatures between 500 and 850 °C at which prominent peaks in the DTA thermogram indicated the formation of various phases. The quenched glass (unannealed specimen) was found to be an insulator. The specimen annealed at 500 °C was found to be semiconducting. The rest were found to be metallic in the normal-conductivity state. All the metallic samples were found to be multiphase.

As the data in the figure suggest, the high-T_c phase forms quite slowly during the anneal. The sluggish reaction kinetics appear to limit severely the utility of the glass-precursor approach to the fabrication of superconductors, particularly of continuous fibers or wires. On heating the glass, the $Bi_2Sr_2Ca_0Cu_1O_6$ (2201) phase precipitates out first, follwed by the T_c = 80 K phase, $Bi_2Sr_2Ca_1Cu_2O_8$ (2212), at higher temperature. The T_c = 110 K phase, $Bi_2Sr_2Ca_2Cu_3O_{10}$ (2223), is formed at temperatures just below the melting temperature, probably by reaction between the 2201 and 2212 phases and the residual calcium and copper oxides. Even after the 243-h anneal, appreciable 2212 phase remains.

This work was done by Narottam P. Bansal and D. E. Farrell of **Lewis Research Center**. *For further information, Circle 130 on the TSP Request Card. LEW-15005*



The **Resistivity of $Bi_{1.5}Pb_{0.5}Sr_2Ca_2Cu_3O_x$** is a function of temperature. Samples were annealed in air at 840°C for different times.

Computer Programs

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If you don't find a program in this issue that meets your needs, call COSMIC directly for a free review of programs in your area of interest. You can also purchase the annual *COSMIC Software Catalog*, containing descriptions and ordering information for available software.

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Computer Programs

These programs may be obtained at a very reasonable cost from COSMIC, a facility sponsored by NASA to make computer programs available to the public. For information on program price, size, and availability, circle the reference number on the TSP and COSMIC Request Card in this issue.

Materials

Designing Catalytic Monoliths for Closed-Cycle CO_2 Lasers

The LASCAT program enables a designer to determine quickly the consequences of changes in design.

Pulsed carbon dioxide lasers are useful in many areas, including aeronautics, research in outer space, and monitoring weather. Most applications require closed-cycle carbon dioxide lasers, which are more portable and self-sustaining than are open-cycle lasers. Without a fresh supply of carbon dioxide and provisions for disposal of byproducts, a closed-cycle laser must recycle the carbon monoxide and oxygen gas produced by the lasing of carbon dioxide. The recombination of the carbon monoxide and oxygen to form a constant supply of carbon dioxide requires an active catalyst, which must be carefully designed to optimize the performance of the laser in accordance with design requirements specific to the application. The LASCAT (Design of Catalytic Monoliths for Closed-Cycle Carbon Dioxide Lasers) computer program aids in the design of a catalyst in a monolith by simulating the effects of design decisions on the performance of the laser.

In a portable laser system, considerations of size, weight, and cost are critical. LASCAT provides the opportunity for the designer to explore tradeoffs among the activity and dimensions of the catalyst, the dimensions of the monolith, the pressure drop caused by the flow of gas through the monolith, the conversion of oxygen, and other variables. The program uses a flexible, simplified model of the catalyst in the monolith to determine the bulk-average gas temperature, composition, and pressure of the gas along its length. The user specifies values for the several parameters that define the operating conditions of the catalyst, including the dimensions of the monolith, the gas at the inlet, thermal properties in operation, and properties of the catalyst. LASCAT provides results that indicate whether the experimental design meets such constraints defined by the user as limits on the rate of conversion, maximum temperature of the gas, and the weight of the monolith.

LASCAT is written in FORTRAN 77 and is designed for use with any text or character-based terminal or computer display. The program requires roughly 40 KB of memory. LASCAT was developed in 1989. LASCAT is restricted to use by U. S. citizens only.

This program was written by Keith Guinn, Richard K. Herz, Seth Goldblum, and Ed Noskowski of University of California, San Diego, for **Langley Research Center**. *For further information, Circle 151 on the TSP Request Card. LAR-14190*

Mechanics

Composite-Blade Structural Analyzer

COBSTRAN computes stresses in blade-like structural components.

The COBSTRAN (COmposite Blade STRuctural ANalyzer) computer program is a preprocessor and postprocessor that facilitates the design and analysis of composite turbofan and turboprop blades, and

of composite wind-turbine blades. COBSTRAN combines the theories of the mechanics of composites and of laminates with a data base of fiber and matrix properties.

As a preprocessor for NASTRAN or another finite-element-method (FEM) program, COBSTRAN generates an FEM mathematical model with anisotropic, homogeneous material properties. The stress output from the FEM program is provided as input to the COBSTRAN postprocessor. The postprocessor then uses the composite-mechanics and laminate-theory routines to calculate individual ply stresses, strains, interply stresses, through-the-thickness stresses, and failure margins.

COBSTRAN is designed to carry out the many linear analyses required for the efficient mathematical modeling and analysis of bladelike structural components made of multilayered angle-plied fiber composites. Components made from isotropic or anisotropic homogeneous materials can also be modeled as special cases in COBSTRAN. NASTRAN MAT1 or MAT2 material cards are generated according to properties supplied by the user.

COBSTRAN is written in FORTRAN 77 and was implemented on a CRAY X-MP computer with a UNICOS 5.0.12 operating system. The program requires either COSMIC NASTRAN or MSC NASTRAN as a structural-analysis software package. COBSTRAN was developed in 1989 and requires a memory of 262,066 64-bit words.

This program was written by R. A. Aiello and C. C. Chamis of **Lewis Research Center**. *For further information, Circle 131 on the TSP Request Card.* *LEW-14992*

Machinery

Program Aids Design of Fluid-Circulating Systems

CASE/A facilitates analysis of environmental-control and life-support systems of spacecraft.

The design and analysis of environmental-control and life-support systems (ECLSS) and active thermal-control systems (ATCS) for spacecraft missions require powerful software that is flexible and responsive to the demands of particular projects. The Computer Aided Systems Engineering and Analysis (CASE/A) program is an interactive software tool for trade study and analysis, designed to increase productivity during all phases of systems engineering. The graphics-based command-driven software package provides a user-friendly computing environment in which the engineer can analyze the performance and interface characteristics of an ECLS/ATC system. The software package is useful during all phases of a spacecraft-design program, from initial conceptual design trade studies to the actual flight, including pre-flight prediction and in-flight analysis of anomalies.

The CASE/A computer program consists of three fundamental parts: (1) the schematic-management system, (2) the data-base-management system, and (3) the simulation-control-and-execution system. The schematic-management system enables the user to construct a model of a system graphically by arranging icons that represent components of the system and connecting the icons to represent the physical fluid streams. Version 4.1 contains 51 fully coded and documented default component routines. New components can be added by the user through the "blackbox" component option. The data-base-management system supports the storage and manipulation of data on components, outputs, and solution criteria through interactive editing screens. The simulation-control-and-execution system initiates and controls the iterative solution process, displaying time statuses and any necessary diagnostic messages.

In addition to these primary functions, the program provides functions in three other important areas: (1) management of the outputs of mathematical models, (2)

system-utility commands, and (3) capacity for user operations logic. The model-output-management system provides the capability for tabular and graphical outputs. Complete data on the mass fractions and properties of fluid constituents (mass flow, pressure, temperature, specific heat, density, and viscosity) are generated at output intervals selected by the user and stored for reference. The Integrated Plot Utility (IPU) provides the capability of plotting all output data. System-utility commands are provided to enable the user to operate more efficiently in the CASE/A environment. The user is able to customize a simulation through optional operations FORTRAN logic. This code developed by the user is compiled and linked with a CASE/A mathematical model and enables the user to control the parameters of operation of components and assign those parameters to time lines during various phases of the iterative solution process.

CASE/A provides for transient tracking of the constituents of a flow stream and for determination of thermodynamic state of the constituents throughout an ECLSS/ATCS simulation, performing analyses of the transfer of heat, chemical reactions, mass and energy balances, and drops in pressure, on the basis of conditions of operation as specified by the user. The program tracks each constituent through all combination and decomposition states while maintaining a mass and energy balance on the overall system. This enables rapid assessment of designs of ECLSS; of the effects of alternate technologies; and of effects caused by changes in metabolic forcing functions, by the usage of consumables, and by system-control considerations.

CASE/A is written in FORTRAN 77 for the DEC VMX/VMS series of computers and requires 12 Mb of disk storage and a minimum paging file quota of 20,000 pages. The program operates on the Tektronix 4014 graphics standard and VT100 text standard. The program requires a Tektronix 4014 or later graphics terminal, a third party composite graphics/text terminal, or a personal computer loaded with appropriate VT100/TEK 4014 emulator software. The use of composite terminals or personal computers with popular emulation software is recommended for enhanced CASE/A operations and general ease of use. The program is available on an unlabeled 9-track, 6,250-bit/in. (15,875-bit/ cm) magnetic tape in DEC VMS backup format. The development of CASE/A began in 1985 under contract to NASA/Marshall Space Flight Center. The latest version (4.1) was released in 1990.

Tektronix and TEK 4014 are trademarks of Tektronix, Inc. VT100 is a trademark of Digital Equipment Corp.

This program was developed by Allen Bacskay of **Marshall Space Flight Center** *and Robert Dalee of McDonnell Douglas Corp. For further information, Circle 149 on the TSP Request Card. MFS-28573*

Fabrication Technology

Program Helps To Optimize Assembly Sequences

FAST evaluates sequences for the assembly of the Space Station *Freedom*.

FAST is a project-management software tool designed to optimize the sequence of assembly of the Space Station *Freedom*. An appropriate assembly sequence involves the coordination of requirements with respect to engineering, design, utilization, availability of transportation, and operations. Because complex designs tend to change frequently, FAST assesses effects of detailed changes upon the system and produces output metrics that identify preferred assembly sequences.

FAST incorporates Space-Shuttle integration, Space-Station hardware, on-orbit operations, and governing programmatic considerations as either precedence relations or numerical data. Hardware-sequencing information can either be put in directly and evaluated via the "specified" mode of operation or be evaluated from

the input precedence relations in the "flexible" mode.

In the "specified" mode, FAST takes as its input a list of the cargo elements assigned to each flight. The program determines those positions of the cargo elements that maximize the margin on the center of gravity. These positions are restricted by the geometry of the cargo elements and the location of attachment fittings both in the Space Shuttle and on the cargo elements. FAST calculates every permutation of locations of cargo elements according to their heights, locations of trunnion fittings, and required distances between cargo elements. Each cargo element is tested in both its normal and reversed orientation (rotated 180°). The best solution is considered to be the one that maximizes the margin on the center of gravity for each flight.

In the "flexible" mode, FAST begins with the first flight and determines all feasible combinations of cargo elements according to mass, volume, extravehicular activity, and constraints imposed by precedence relations. The program generates an assembly sequence that meets mass, volume, position, extravehicular-activity, and precedence constraints while minimizing the total number of Shuttle flights required.

Issues associated with ground operations, performance of spacecraft, logistical requirements, and users' requirements will be addressed in future versions of FAST.

FAST is written in the C language and has been implemented on DEC VAX-series computers running VMS. The program is distributed in executable form. The source code is also provided, but it cannot be compiled without the Tree Manipulation Based Routines (TMBR) package from NASA's Jet Propulsion Laboratory, which will be available from COSMIC in the future. The main memory requirement is based on the data used to drive the FAST program. All applications should be easily run on a computer that has 10 Mb of main memory. FAST was developed in 1990.

DEC, VAX, and VMS are trademarks of Digital Equipment Corp.

This program was written by Chester S. Borden, David G. Werntz, and Steven J. Loyola of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 1 on the TSP Request Card.*
NPO-18462

Mathematics and Information Sciences

C Language Integrated Production System, Ada Version

Ada is used as the source language.

The C Language Integrated Production System, CLIPS, is a software shell for the development of expert-system computer programs. It is designed to enable research on, and the development and delivery of, artificial-intelligence software by use of conventional computers. The primary design goals for CLIPS are portability, efficiency, and functionality. CLIPS/Ada provides the capabilities of CLIPS v4.3 but uses Ada as the source language for the CLIPS executable code.

CLIPS/Ada implements a forward-chaining rule-based language. The program contains an inference engine and a language syntax that provide a framework for the construction of an expert-system program. It also includes features for debugging an application program. CLIPS/Ada is based on the Rete algorithm, developed by C. L. Forgy, which provides a very efficient method for performing repeated matching of patterns.

A CLIPS program consists of facts and rules called productions. The collection of conditions and actions to be taken if the conditions are met is constructed into a rule network called a production system. As facts are asserted either prior to or during a session, CLIPS/Ada matches patterns in a number of fields. Wild cards and variables are supported for both single and multiple fields. CLIPS/Ada allows the inclusion of subprograms defined by the user (outside functions that may be written in a language other than Ada). CLIPS/Ada itself can be embedded in an Ada program such that the expert system is available as a simple subroutine call.

The CLIPS/Ada program is written in Ada for interactive execution and should work on any workstation-class or larger computer with a validated Ada compiler. The program has also been compiled on a 386-based personal computer with 4 MB of random-access memory and the Alsys v4.3-1 Ada compiler. The standard distribution medium contains only the archived source code and the program to uncompress it. The documentation consists of the Advance Programming Guide and the Architecture Manual. Beginning users of CLIPS should purchase the C-language CLIPS v4.3 documentation (MSC-21208) separately for the User's Guide (a tutorial) and the complete Reference Manual. CLIPS was developed in 1986, and Version 4.3 was released in June of 1989. CLIPS/Ada was released in August of 1990.

This program was written by Chris Culbert, Gary Riley, and Robert T. Savely of **Johnson Space Center**, *Clovis J. Melebeck, Wesley A. White, Terry L. McGregor, and Melisa Ferguson of Barrios Technology Inc., and Reza Razavipour of Computer Sciences Corp. For further information, Circle 16 on the TSP Request Card.*
MSC-21825

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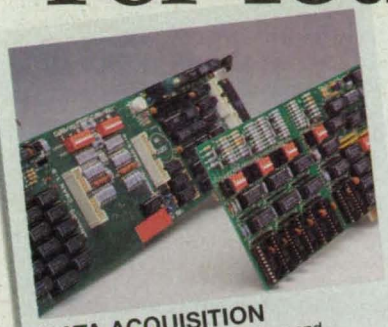

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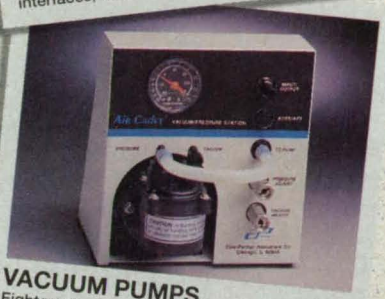

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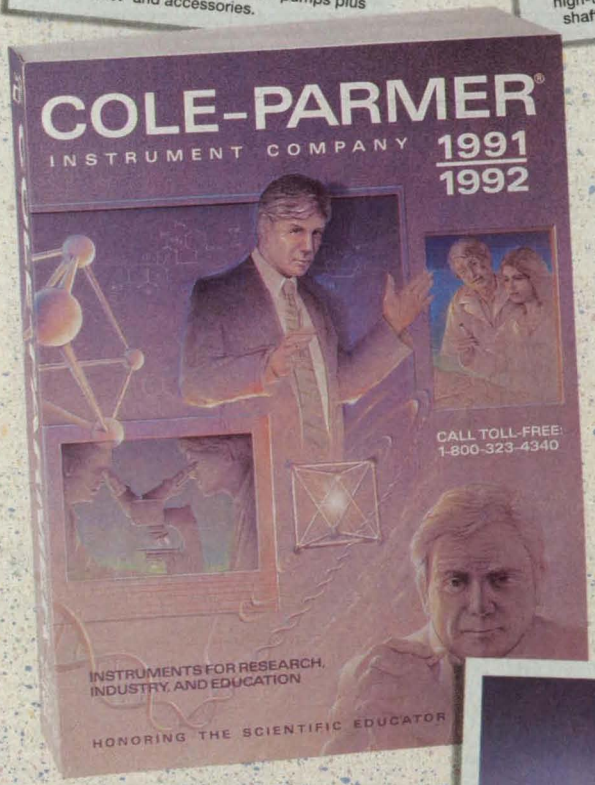

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Mechanics

Torque Tube Stiffens Trailer Frame

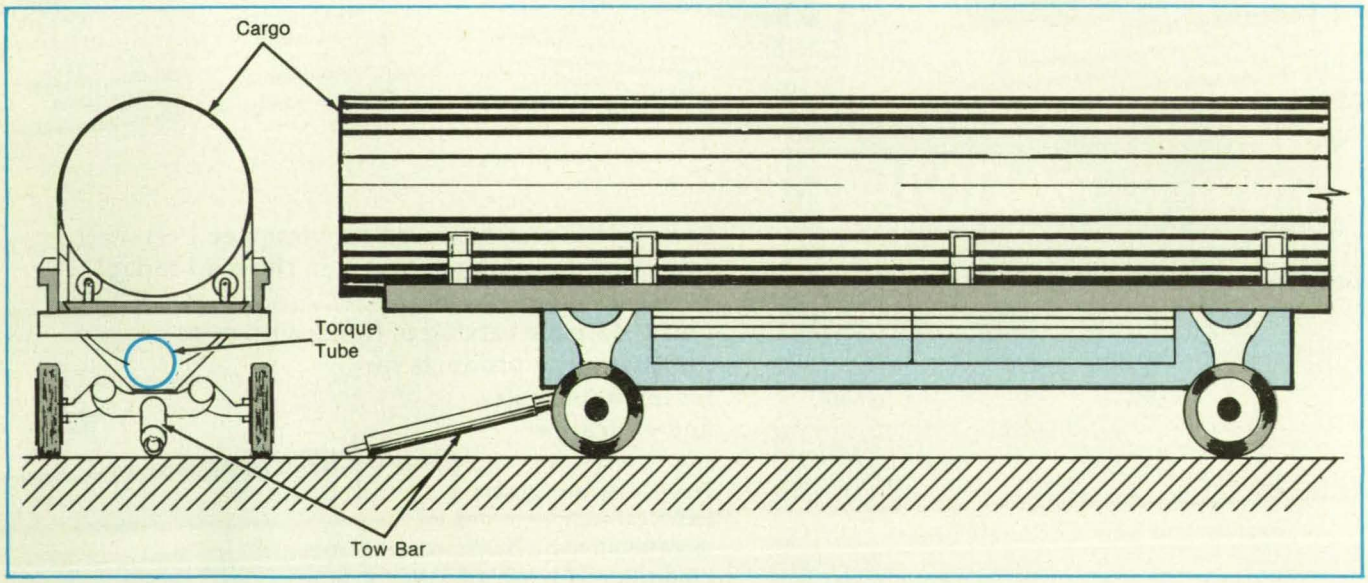
The tube isolates the cargo from twisting moments.

NASA's Jet Propulsion Laboratory, Pasadena, California

A reinforced trailer frame absorbs torsion, preventing it from being transmitted to the cargo. The reinforcement is needed in this particular trailer because it is of hard-axle design, without springs or shock absorbers.

The trailer frame incorporates a longitudinal torque tube that absorbs torsional loads and stiffens the trailer (see figure). The torsion frame can be used to transport large cylindrical objects like pressure vessels, tanks, and rocket engines without subjecting them to damage or excessive loads.

This work was done by Malcolm J. MacMartin of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 41 on the TSP Request Card.*
NPO-18314



The **Torque Tube Is Held** by plates over the axles.

Low-Hysteresis Flow-Through Wind-Tunnel Balance

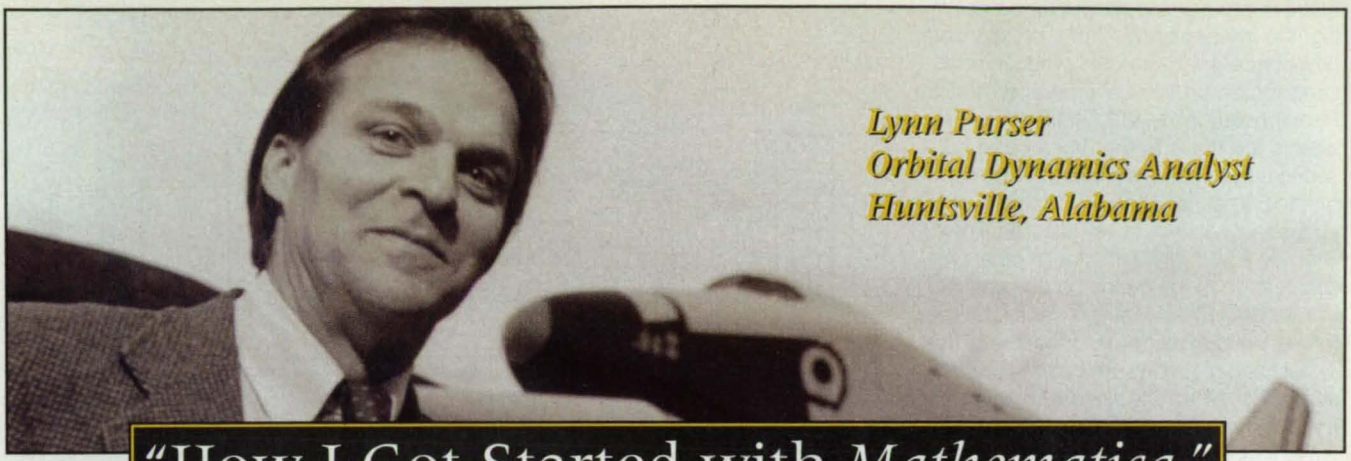
Symmetrical forces caused by internal flow are cancelled.

Ames Research Center, Moffett Field, California

An improved flow-through wind-tunnel balance (see figure), which is less subject to hysteresis and spurious force readings than prior devices of this type, has been designed, fabricated, and tested. A wind-tunnel balance serves to mount a model aircraft on a sting in a wind tunnel and to measure the forces exerted on the model by the wind-tunnel flow. Compressed air or another pressurized fluid is fed from a passage in the sting through the internal passages of a flow-through wind-tunnel balance to supply power to the model. The improved flow-through wind-tunnel balance is designed to minimize the antisymmetrical spurious forces caused by the internal flow and to provide for measurement and correction of what little spurious forces remain.

A typical wind-tunnel balance of prior design includes a metric portion, to which the model is attached; a nonmetric portion, which is attached to the sting; and a metric break, which connects the metric and nonmetric portions. In this balance, frame elements of the nonmetric and metric portions and a set of flexure beams that connect them are all made together in one piece by electrical-discharge machining. In prior balances, mechanical hysteresis has arisen in part because these parts were made as separate pieces that were fastened mechanically and, therefore, could move with respect to each other. The one-piece construction of the metric break in this balance eliminates hysteresis for most practical purposes.

The pressurized fluid enters the balance along the common axis of the balance and the hollow sting. A bellows assembly seals



Lynn Purser
Orbital Dynamics Analyst
Huntsville, Alabama

"How I Got Started with *Mathematica*®"

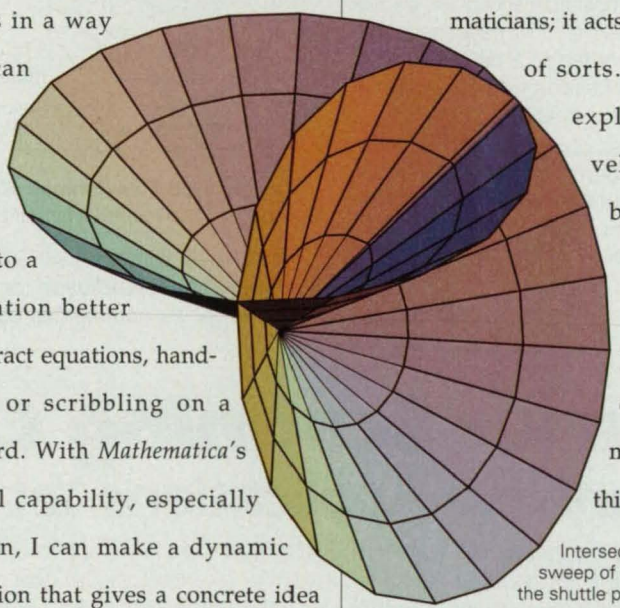
I admit, when I first read about *Mathematica*, I was a little skeptical. I guess mathematicians are like anybody else. Sort of like auto workers being replaced by robots—some mathematicians were skeptical of something that might replace them. So when my firm offered an in-house training seminar on *Mathematica*, I decided to see what all the talk was about.

Photo Courtesy of NASA

That class was fun. I tried to do things beyond what the teacher was covering—the rudimentary stuff about *Mathematica* syntax. I wanted to do animation and play with the graphics. I was taken with the visual dimension of it.

Working on NASA projects, I have to solve problems and present my solutions in a way others can understand. People respond to a visualization better than abstract equations, hand-waving, or scribbling on a blackboard. With *Mathematica*'s graphical capability, especially animation, I can make a dynamic presentation that gives a concrete idea of what I'm talking about.

Then there's the symbolic power. For example, the first project I tackled with *Mathematica* involved a nasty algebraic equation. I solved it on my own and then let *Mathematica* solve it. We both came up with the same answer. But my solution took a few hours and *Mathematica*'s took a few minutes.



Intersection of fields of sweep of two sensors in the shuttle payload bay.

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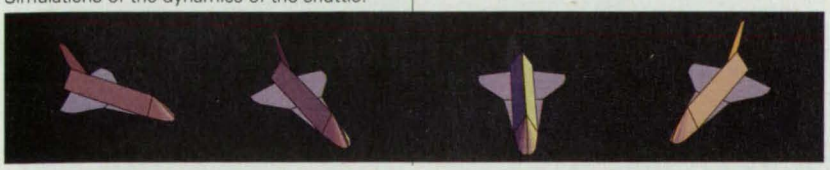
Simulations of the dynamics of the shuttle.



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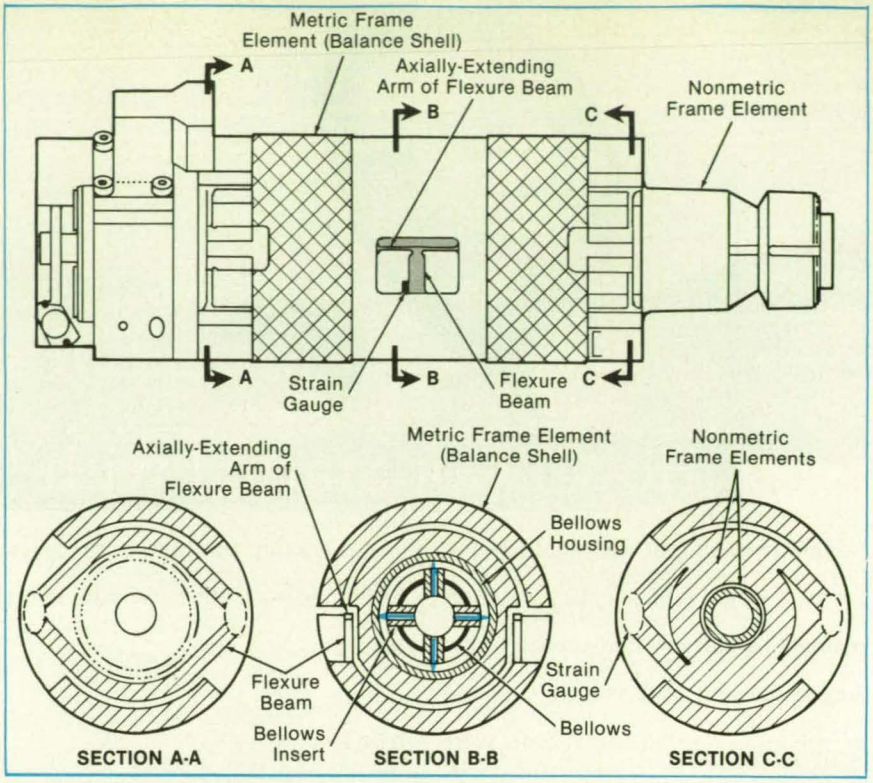
those unpressurized passages surrounding the metric break from pressurized flows because they would produce undesired forces on the balance and model. Radial holes in a set of bellows inserts directs the flows to the pressurized passages across the metric break in a symmetrical manner that, in principle, produces zero net force in any direction. Thereafter, the flow is directed through other passages through the metric portion and into the model. Strain gauges measure the forces on the model by measuring the deflections of the flexure beams, and are so positioned on the flexure beams that the symmetrical forces caused by the internal flow result in zero net force readings.

To the degree to which residual effects of temperature, pressure, and internal flow give rise to spurious asymmetrical forces and force readings, it is desirable to correct for them. For this purpose, a pressure sensor and a temperature sensor are placed in one of the internal flow passages, and their outputs are fed to a data-reduction program for processing that corrects the strain-gauge force readings.

This work was done by N. Kunz, P. M. Luna, A. C. Roberts, and R. C. Smith of **Ames Research Center** *and W. L. Horne and K. M. Smith of Micro Craft, Inc. For further information, Circle 52 on the TSP Request Card.*

This invention has been patented by NASA (U.S. Patent No. 4,845,993). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Ames Research Center [see page 16]. Refer to ARC-11877.



The **Improved Flow-Through Wind-Tunnel Balance** includes features that minimize both spurious force readings caused by the internal pressurized flow and mechanical hysteresis.

Specimen Holder for Flammability Tests

A frame and clamps are designed to minimize local overstress on the specimen.

Lyndon B. Johnson Space Center, Houston, Texas

A fixture holds sheet specimens for flammability tests. It applies a nearly uniform local clamping pressure around the edges but accommodates changes in thickness caused by heating, without tearing or breaking the specimen. It accepts films, fabrics, foams, and other sheets, rigid or flexible. The specimens may be thin or thick, or of variable thickness. The heat capacity of the fixture is relatively low in comparison with that of prior, bulkier fixtures made for the same purpose: consequently, the new fixture interferes less with the interpretation of results of a test by drawing less heat away from the specimen.

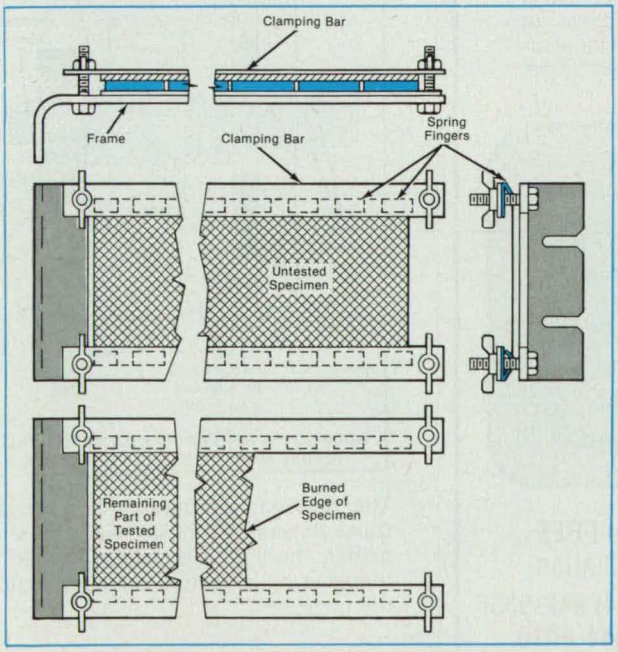
The fixture includes a frame that has two parallel arms, a U-shaped holder, two strips of spring material segmented into finger springs, two clamping bars, bolts and wingnuts. The parts are made of stainless steel except for the spring clamps, which are made of beryllium copper because of its spring properties and its resistance to fatigue and flames.

A sheet specimen is placed on the arms of the holder, and a spring-clamp strip is laid over the specimen on each arm. Then a clamping bar is laid over each spring-clamp strip and bolted in place (see figure). Flammability testing can then proceed.

As the specimen burns, the spring fingers in contact with the remaining portion of the specimen continue to hold the specimen. If the specimen shrinks or swells in thickness, the fingers remain spring-loaded against the specimen, continuing to hold it with nearly constant force. Because they maintain contact along only a thin line, they conduct little heat from the specimen.

The frame could be designed to hold specimens of a variety of shapes and sizes. It could be bent to accommodate curved rigid specimens. It could also be used for such other tests as particle-impact tests.

This work was done by Michelle A. Rucker of **Johnson Space Center**. *For further information, Circle 107 on the TSP Request Card. MSC-21798*



Independent Spring Fingers hold the specimen on the arms of the frame.

Adjustably Preloaded Quick-Release Pin

An easy-to-use fastening device is adapted from a commercial product.

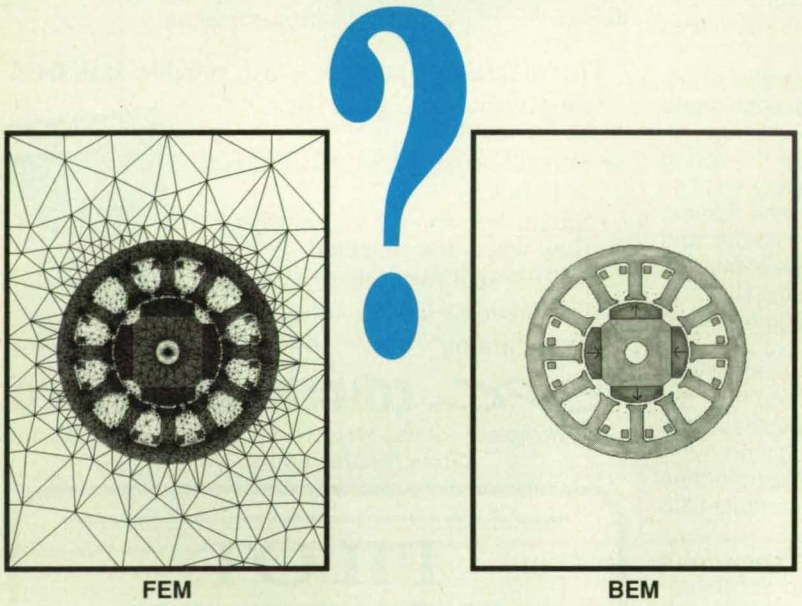
Lyndon B. Johnson Space Center, Houston, Texas

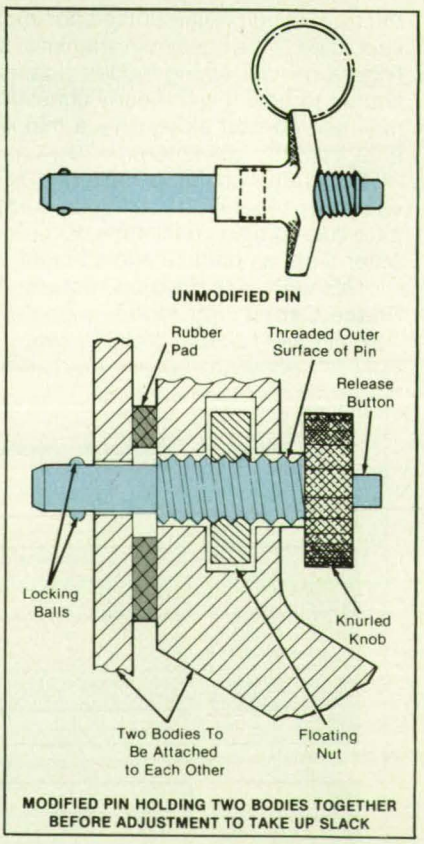
An attachment pin connects and disconnects rapidly and can be adjusted to accommodate small differences between the thicknesses of nominally identical sets of parts to be attached to each other. The pin is a modified version of a commercial ball-locking fastener that is sometimes called a "pip" pin.

In its modified form, the pin can be preloaded slightly in tension as though it were a bolt. The T-shaped handle of the unmodified version is removed from the threaded end of the pin opposite the locking-ball end. In its place, a knurled knob is secured with a setscrew on a flat spot on the otherwise threaded surface. A floating nut that fits into a slot on one of two bodies that are to be attached to each other engages the threaded surface on the pin.

To insert the pin, the user presses the button on the end of the pin opposite the balls to retract the balls, places the pin through the two bodies to be attached to each other, and releases the button to push the balls back out to the locking position. The user then turns the knurled knob to thread the pin in the floating nut until the slack is taken up, and rubber pads between the bodies to be attached to each other are compressed slightly. To extract the pin, the user simply presses the button to retract the locking balls and pulls the pin out.

This work was done by Harold W. Reimers of **Johnson Space Center**. *For further information, Circle 48 on the TSP Request Card.*
MSC-21753





MODIFIED PIN HOLDING TWO BODIES TOGETHER BEFORE ADJUSTMENT TO TAKE UP SLACK

The **Modified Adjustable-Grip-Length Quick-Release Pin** holds two bodies together. The threaded shaft of the pin is threaded in the floating nut to pretension the fastener.

Fiber Jackets for Vibration-Damping Struts

Weak structural elements would be protected from overloads by braided fibers.

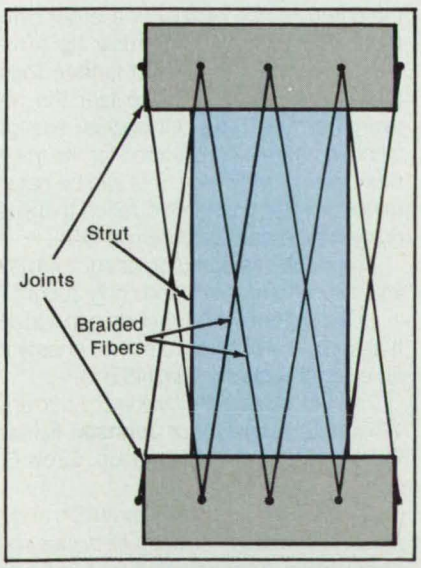
NASA's Jet Propulsion Laboratory, Pasadena, California

Fiber jackets have been proposed for use in protecting elastomeric and other vibration-damping struts against excessive loads. Such struts can be damaged by excessive stretching in transit, during which loads and displacements can exceed the relatively small displacements for which the struts were designed.

A typical proposed jacket would consist of braided fibers (see figure) of a material (e.g., graphite or a suitable polymer) of high specific strength. Although unidirectional fibers could be used instead, braided fibers would be preferred because of the greater ease with which a braided-fiber jacket can be manufactured, handled, and attached to structural joints at the ends of a strut. On the other hand, a comparable jacket of straight fibers could carry a load 5 to 10 percent larger.

Friction between braided fibers would give rise to a hysteresis in the stress-versus-strain behavior of a jacket. The hysteresis would enhance the absorption of large vibrations.

A jacket would absorb only tensile loads. To protect a strut against both high compressive and high tensile loads, it would be necessary to install two fiber jackets, supported from opposite lengthwise directions.



A **Jacket of Braided Fibers** would be fastened to structural joints at the ends of a strut. The jacket would carry excessive tensile loads, partly bypassing the strut.

This work was done by Benjamin P. Dolgin of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 8 on the TSP Request Card.*
NPO-18161

Blast-Absorbing Bag

Stitches rip to dissipate explosive energy.

Lyndon B. Johnson

Space Center, Houston, Texas

A proposed expandable bag would contain debris from an explosion. The bag could permanently surround a vessel or devices prone to explosive disintegration (e.g., a pressurized tank), or it could be slipped around a small bomb.

The bag would consist of cells of a strong,

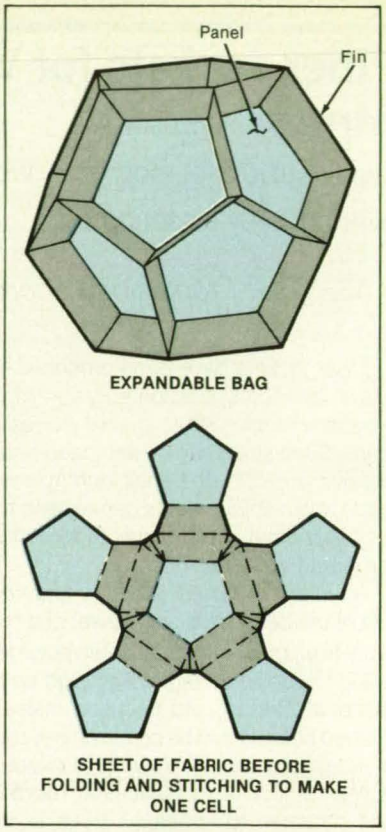
Finned Cells would be shaped like outward-opening cups. Cells would be built up from overlapped sheets of fabric and stitched together to form an expandable polyhedral bag. Cells may be pentagonal, as shown here, or else triangular or square.

flexible fabric like Kevlar (or equivalent) aromatic polyamid, stitched together to form an externally finned polyhedron (see figure). Each cell would be made of contiguous sheets of fabric, cut, folded, and stitched together in overlapping layers.

When an explosion occurred within the bag, sets of stitches would be ripped in progression by the expanding gas, absorbing the energy of the explosion as they tore. As the stitches in the fins between cells broke, the cells would change from outward-opening cups to inward-opening bubbles. However, the stitches that joined the cells would be stronger and would resist the force of the explosion so that the bag would remain intact and retain the debris of the explosion.

If the bag is to be used to dispose of a bomb, one or more cells must be removable so that the bomb can be placed in it. For this purpose, panels could be equipped with a draw cord, bolt plates, hooks, zippers, or other fastening devices for quick and easy opening and closure.

This work was done by Jon B. Kahn of **Johnson Space Center**. *For further information, Circle 109 on the TSP Request Card. MSC-21666*



Net Catches Debris From Explosion

A device restrains fragments and absorbs their kinetic energy.

Lyndon B. Johnson Space Center, Houston, Texas

A debris catcher uses rip-away stitching to absorb the kinetic energy of fragments driven by a small explosive device. The rip-away principle is also adaptable to restraint belts for vehicles; such belts would subject passengers to more gradual deceleration and less shock than conventional belts do.

The catcher was developed for the emergency escape system in the Space Shuttle, in which a pyrotechnic device is exploded to blast a rectangular hole in the wall of the cabin. The explosion ejects debris that could puncture pressure vessels in the payload bay. The debris catcher prevents this dangerous situation by containing and decelerating the fragments within a short distance.

The catcher consists of a honeycomb plug backed by a folded web of aromatic polyamid fabric (see Figure 1). The plug — made of hexagonal-cell honeycomb aluminum sandwiched between two thin aluminum sheets — is bonded to the bulkhead over the pyrotechnic device. When the pyrotechnic charges are activated, the plug absorbs debris from the cut bulkhead and from the pyrotechnic device. The energy of the particles traveling at 400 ft/s (122 m/s) detaches the plug from the bulkhead and drives it into the net.

The rapidly-moving plug extends the net, tearing the stitches in the net until its kinetic energy is expended (see Figure 2). The rip-away stitching limits the load to a constant level on the bulkhead frame to which the net is attached. The level is independent of the energy of the explosion; a larger pyrotechnic charge would simply rip more stitches and extend the net farther. Thus, the explosion is unlikely to tear the net away from its frame. Of course, enough stitched net must be allowed for the maximum expected energy. This can be determined from a simple calculation that has proved to be quite accurate in tests.

The catcher weighs only about 2.4 lb (1.1 kg). It is compact: it extends only about 1.5 in. (3.8 cm) from the bulkhead when folded. It absorbs the usual pyrotechnic energy in an extension of only 6 in. (15 cm).

This work was done by Jon B. Kahn and William C. Schneider of **Johnson Space Center**. *For further information, Circle 60 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center [see page 16]. Refer to MSC-21562.

Figure 1. The **Net of Stitched Webbing** folds compactly over a honeycomb plug. The net is attached to a frame that mounts on the wall around the rectangular area to be cut out by the explosion.

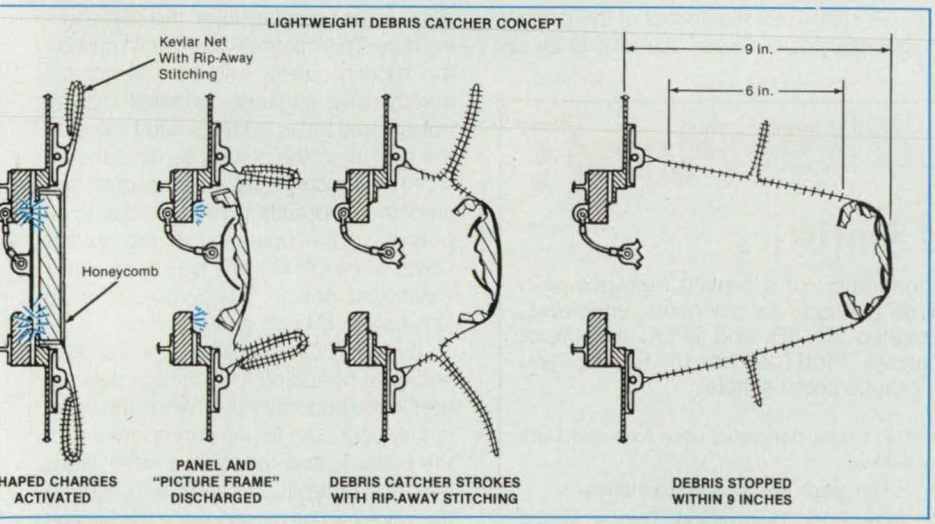


Figure 2. The **Sequence of Events** starts with the explosion of shaped charges. The honeycomb panel absorbs the debris from the explosion and crumples into the net. It dissipates its energy by ripping about 9 in. (15 cm) of stitched net.

Self-Repriming Heat Pipe

The formation of bubbles is inhibited.

Lyndon B. Johnson Space Center, Houston, Texas

A modified heat pipe reprimes itself if bubbles develop in its liquid-return line. Ordinarily, a heat pipe can no longer function when a bubble forms because the bubble blocks further movement of liquid into the evaporator and thus terminates the liquid-to-vapor part of the heat-pipe cycle.

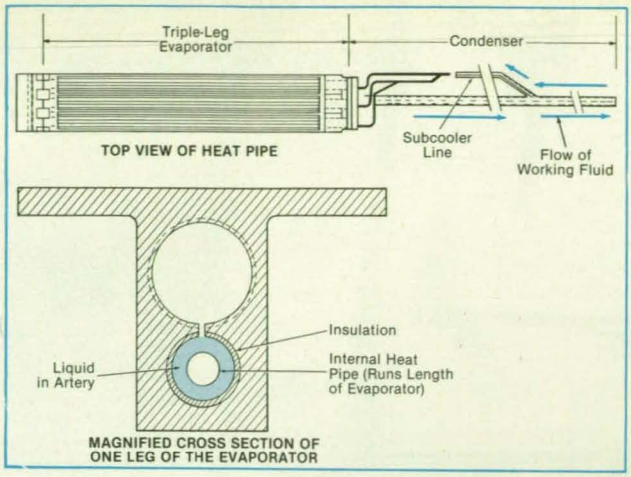
The self-repriming heat pipe intrinsically inhibits the formation of bubbles and quickly eliminates them if they do form. The operation is completely passive: no control mechanisms or additional source of energy are needed. It is therefore well suited to service in a remote, unattended place.

In the self-repriming heat pipe, the liquid artery in the evaporator is surrounded by

insulation and contains a small concentric heat pipe. The liquid flowing in the artery is kept slightly below the boiling temperature by an additional flow of subcooled liquid along a small spur line that branches away from the main body of the liquid artery at the condenser. The small internal heat pipe evens out the distribution of temperature along the artery in the evaporator, helping to keep all the liquid in the artery subcooled. If bubbles form when the liquid evaporates too fast as a result of an excessive load of short duration, the pipe stops functioning temporarily, but the sub cooled bleed flow condenses the bubbles as soon as the load is reduced.

The principle was demonstrated in a large-artery, high-capacity heat pipe 48 ft (14.6 m) long. Bubbles were intentionally induced by operating the pipe well above its rated heat load. The heat pipe failed but reprimed itself when the load was reduced and resumed full-load operation. The unmodified version of this heat pipe would not recover under such circumstances.

This work was done by John Duschatko and John Oren of LTV Missiles and Electronics Group for **Johnson Space Center**. *No further documentation is available.*
MSC-21761



The **Small Spur Line From the Condenser** feeds subcooled liquid to the evaporator in each leg (three legs are shown here). The subcooled liquid, in combination with the insulation in the evaporator artery and a small nonarterial internal heat pipe, maintains the liquid in the artery slightly below the boiling temperature.

Aerodynamic Shutoff Valve

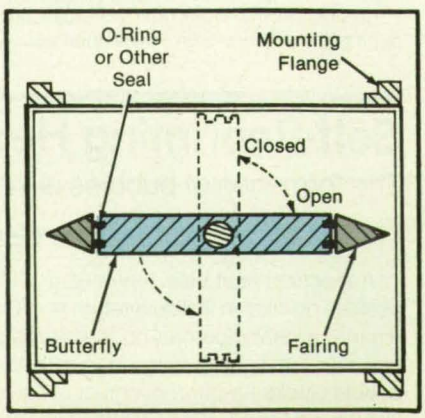
Fairings enhance an internal suction system for porous-wing laminar-boundary-layer control.

Langley Research Center, Hampton, Virginia

Current methods of producing an aerodynamic butterfly valve require a sealing lip for the valve seat or a large butterfly with O-rings or the equivalent. Either design disturbs the flow and generates wakes, resulting in turbulent internal noise. A new design for a shutoff valve dramatically reduces aerodynamic drag and its unwanted effects.

A system for the control of the laminar boundary-layer flow on the wing of an airplane includes a porous wing surface and a suction system inside the wing to draw in external turbulence and prevent the transition of the boundary layer, thereby reducing drag. This control system must provide the suction quietly, with smooth internal aerodynamic surfaces. Turbulent internal noise could travel from a shutoff valve up the system to the porous surface and affect the boundary layer. A flow as quiet and smooth as possible is required during all phases of the operation of the shutoff valve: while the valve is fully open, while it is closed, or while it undergoes a transition between open and closed.

This type of aerodynamic flow has been achieved by adding fixed fairings (see figure) to the butterfly valve. When the valve is fully open, the fairings are aligned with the butterfly and reduce the wake. However, the butterfly is free to turn, so that the valve can be closed, while the fairings remain fixed.



Fixed Fairings Dramatically Reduce Turbulence in the airflow system that includes the butterfly valve.

This design significantly reduces turbulence in the flow of air in the internal suction system. This valve could aid in the development of an improved porous-surface boundary-layer control system to reduce aerodynamic drag. Applications are expected to be primarily aerospace. However, the system can be adapted to boundary-layer control on high-speed land vehicles.

This work was done by Raymond H. Horstman of Boeing Commercial Airplane Co. for **Langley Research Center**. *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Langley Research Center [see page 16]. Refer to LAR-14196.

Quick-Fit Trailer Coupling for a Grader

A cheap modification makes it easy to hitch a heavy trailer.

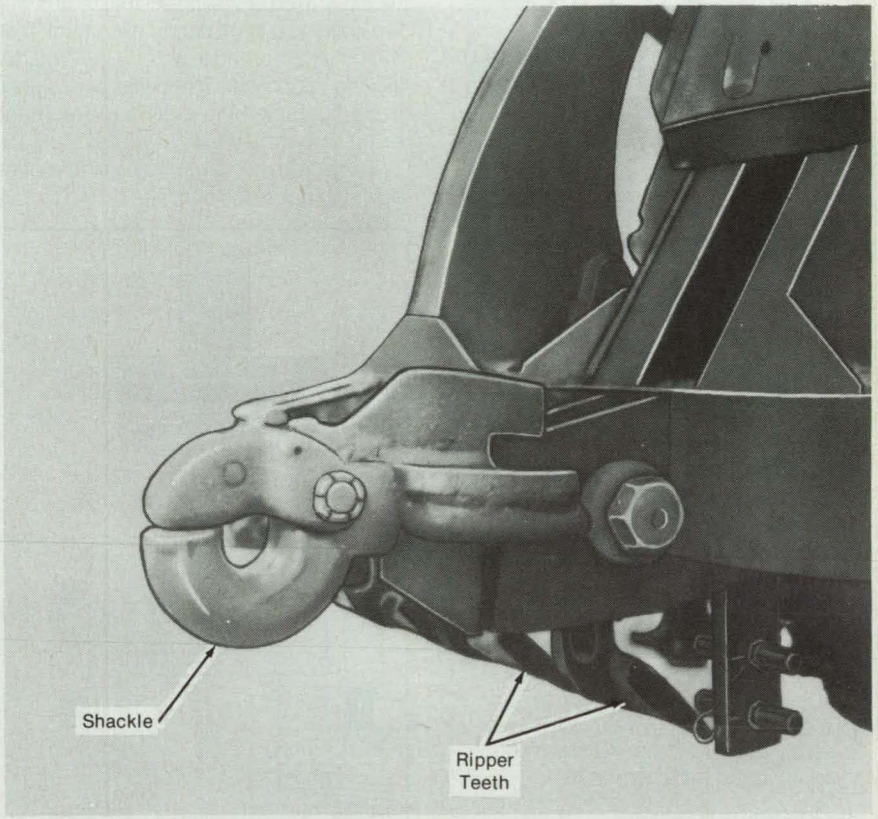
Lyndon B. Johnson Space Center, Houston, Texas

A ripper attachment on a grading tractor has been adapted to lift the tongue of a trailer tow bar hydraulically. The modified ripper makes it unnecessary for the tractor operator to use a jack or fork lift to raise the tongue. The modified ripper attachment enables the tractor operator, acting alone, to hitch the trailer to the tractor, without the expense and complication of a dedicated hydraulic lifting mechanism for a trailer hitch.

The ripper attachment was modified by welding a scrap coupling plate and large shackle to it (see figure). The modification took less than 2 h. For modification of ripper attachments in quantity, the parts could be forged and machined inexpensively.

In preparation for hitching a trailer, the operator simply lowers the modified ripper attachment by use of the hydraulic ripper power until the shackle is aligned with the tongue of the tow bar. The operator slides the tongue into the shackle, closes the shackle, then raises the ripper attachment hydraulically to its normal position to tow the trailer.

This work was done by Terry A. Soper and Calvin T. Moulton of Lockheed Engineering and Sciences Co. for **Johnson Space Center**. *For further information, Circle 5 on the TSP Request Card.*
MSC-21773



The **Modified Ripper Attachment** includes an added plate and shackle for connecting it to a tow bar. The modification was made quickly by use of scrap parts.

Soft-Capture Mechanism for Collet Joint

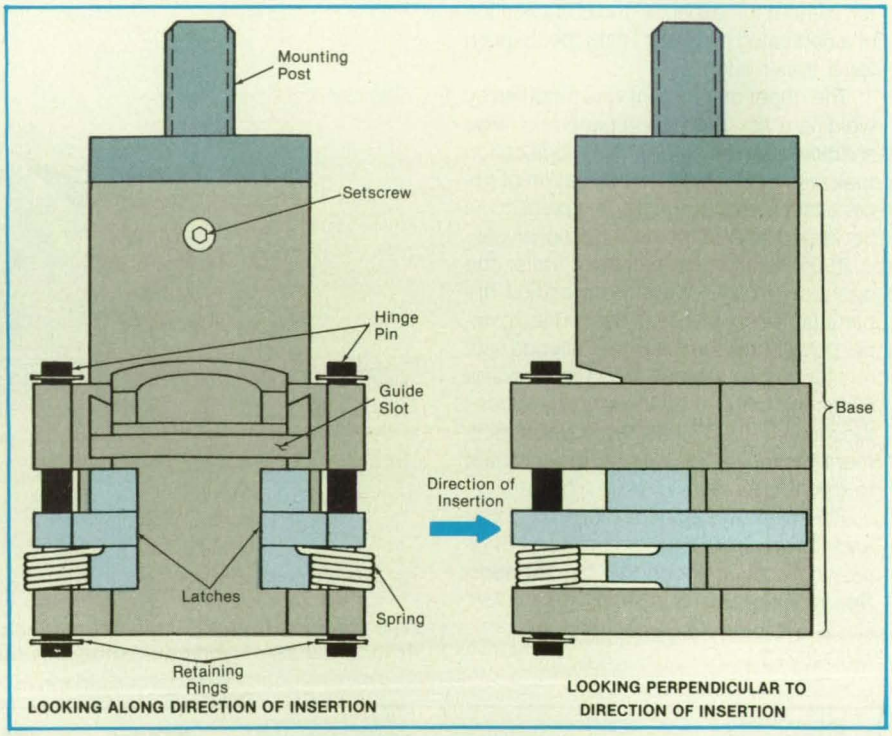
Spring-loaded latches capture a collet loosely.

Lyndon B. Johnson Space Center, Houston, Texas

A soft-capture mechanism is part of a latching-and-rigidifying mechanism that joins a strut rigidly to a node on a truss. The latching-and-rigidifying mechanism is of the spreading-collet type, in which a collet (which is typically fixed on the end of the strut) is inserted into a base (which is typically fixed on the node) that mates with the collet to assure proper alignment, then the collet is spread to rigidify the joint, fixing the alignment. The collet is designed to be operable by a heavily gloved hand or by a robot.

The soft-capture mechanism is mounted in the base and consists of two spring-loaded latches (see figure). During insertion of the collet, a guide ring on the collet (not shown) engages in the guide slot in the base, and the outer casing of the collet is pushed into the base, in the direction shown, between the spring latches. Once the outer casing of the collet is inserted far enough, the latches close around this casing, thereby gently securing the joint (soft capture) until the joint can be rigidified by expansion of the collet.

This work was done by John E. Huff, Jr., of **Johnson Space Flight Center**. *For further information, Circle 108 on the TSP Request Card.* MSC-21735



Spring-Loaded Latches are spread apart by a collet (not shown) as it is inserted into the recess in the base. When the collet has been pushed most of the way in, the latches close in to hold the collet. Then the collet is expanded to lock it into the base and rigidify the connection.

Fractional-Step, Finite-Volume Computation of Flow

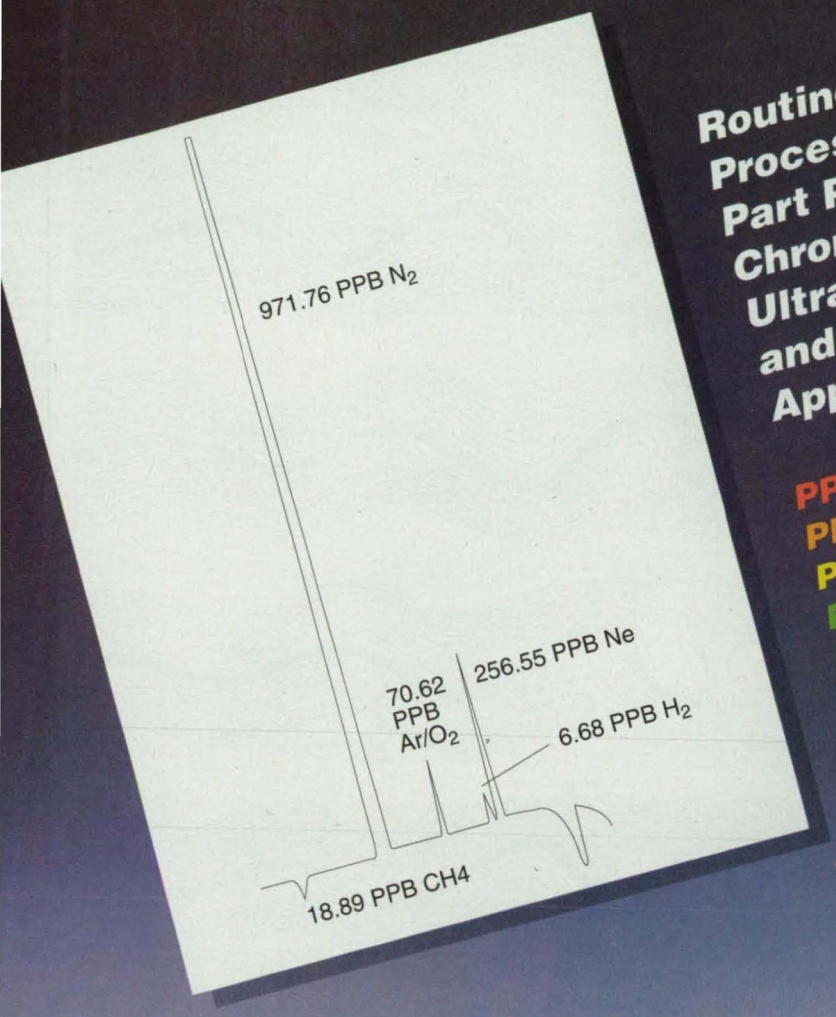
The Navier–Stokes equations of incompressible flow are solved in curvilinear coordinates.

Ames Research Center, Moffett Field, California

A method of solving the Navier–Stokes equations of incompressible flow in general nonorthogonal curvilinear coordinates incorporates the fractional-step and finite-volume approaches. This is one of many methods that have been developed in the continuing effort to achieve accuracy without the need for excessive computation time in the numerical simulation of time-dependent, three-dimensional flows bounded by surfaces of complicated shape.

In the fractional-step approach, the so-

ULTRA TRACE GAS ANALYSIS AT THE POINT OF USE.



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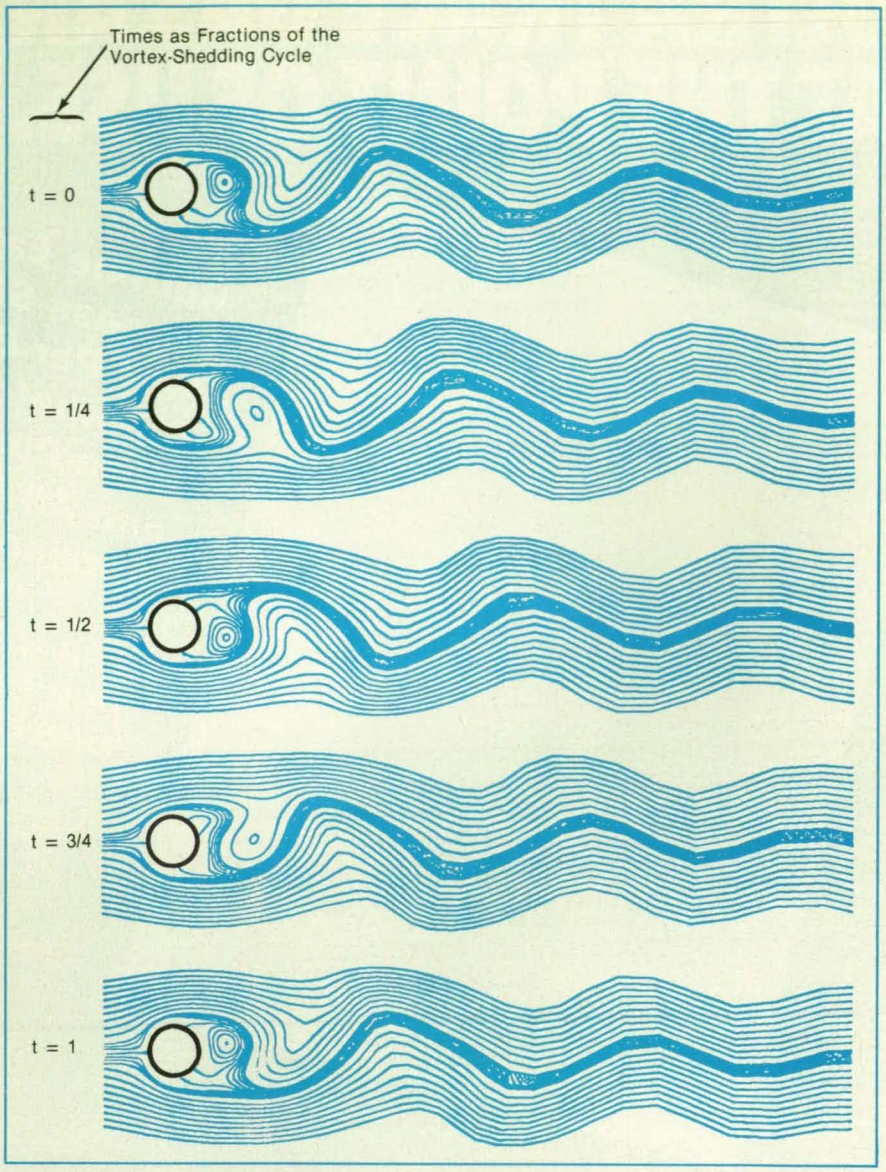
lution is advanced in two stages at each time step. In the first stage, the equations for the conservation of momentum are solved to obtain an approximate velocity field that is not necessarily free of divergence; that is, does not satisfy the equation of continuity (representing the conservation of mass) of an incompressible fluid. In the second stage, the pressure and velocity fields are corrected to satisfy the equation of continuity. This requires the solution of a Poisson equation with Neumann boundary conditions (normal derivatives specified on the boundaries).

In the finite-volume approach in general, the physical region is divided into cells denoted by the body-fitted or other curvilinear coordinate grid, and the basic equations of flow are stated as integrals over the volumes and surfaces of the cells. This particular finite-volume approach proceeds from a primitive-variable formulation in which the pressure at the center of each cell and the volume flux across the faces of each cell (instead of the Cartesian components of velocity, as is customary) are the dependent variables. This is equivalent to using the contravariant components of velocity in a staggered grid multiplied by the volumes of the computational cells, and it makes possible a simple extension of the staggered-grid spatial discretization to general curvilinear coordinates. By this choice of variables, the discretized equation for the conservation of mass can be satisfied easily, and the convergence of the computation toward the solution of the Poisson equation is enhanced.

The fractional-step approach is combined with an approximate factorization of the equations for the conservation of momentum in a way that permits the use of the physical boundary conditions. An efficient algorithm solves the Poisson equation in general nonorthogonal coordinates by use of a consistent discrete approximation. The discrete approximation of the equations of flow is accurate to second order in both time and space, except that the pressure is computed by an approximation that is accurate to only first order in time.



The Computed, Time-Dependent, Two-Dimensional Flow about a circular cylinder was computed for an incompressible fluid with a Reynolds number of 200. This succession of streamlines illustrates the flow at various stages of one vortex-shedding cycle.

The method has been tested by using it to compute various steady and unsteady flows (see figure). The computed flows agree well with those of other computations and with experimental flows over a wide range of Reynolds numbers.

This work was done by Dochan Kwak of **Ames Research Center**, *Moshe Rosenfeld of MCAT Institute, and Marcel Vinokur of Sterling Software. For further information, Circle 20 on the TSP Request Card.*

ARC-12621

Books and Reports

These reports, studies, handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Trajectory and Heating of a Hypervelocity Projectile

An approximate velocity-versus-density relationship is derived.

A technical paper presents the derivation of an approximate, closed-form equation for the relationship between the velocity of a projectile and the density of the atmosphere (or, equivalently, of the altitude). While the exact equations of motion can be integrated numerically for specific cases, the approximate equation aids in the development of physical insight. The results of calculations based on the approximate equation agree well with results from numerical integrations of the exact equations of motion. Comparisons of these results are presented in a series of graphs.

The theoretical projectile is a cylinder with a hemispherical nose. It is launched from the surface of the Earth at a velocity high enough that a significant fraction of the initial speed is retained high in the atmosphere or upon leaving the atmosphere. Equations for the forces upon the projectile and the rate of heating are presented. A crucial step in the derivation of the approximate equation of motion is the truncation of the infinite series for the integrand in the equation for the heating of the projectile.

The equation for the trajectory is used to calculate maximum decelerations of the projectile and stagnation pressures parametrically for initial velocities ranging from 2 to 6 km/s. At 6 km/s, the peak decelera-

tion is about 282 times normal gravitational acceleration, and the peak stagnation pressure is nearly 440 atm (45 MPa).

The heating at the stagnation point is calculated parametrically for both a nonablating (i.e., "cold") wall and for an ablating carbon surface. Expressions are derived for the rate of heating at the stagnation point and for the total heat per unit area at the stagnation point delivered to the projectile throughout the flight. Although the peak rate of heating can be very high (e.g., nearly 18 kW/cm^2 at a speed of 6 km/s and a nose radius of 5 cm), the rate decays to one-tenth the initial value within 3 seconds. For the most severe case calculated, the total heat per unit area delivered to a carbon ablator at the stagnation point is 35 kJ/cm^2. However, the required mass of the heat shield in the nose region is conservatively estimated to be only about 1 percent of the total mass of the projectile.

This work was done by Michael E. Tauber of **Ames Research Center**. *Further information may be found in NASA TP-2614 [N88-19412], "Trajectory Characteristics and Heating of Hypervelocity Projectiles Having Large Ballistic Coefficients."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center [see page 16]. Refer to ARC-11805.

Dual-Potential Formulation of Navier-Stokes Equations

The dual-potential method is extended to unsteady flows of compressible, viscous fluids.

A report discusses research on a dual-potential formulation of the Navier–Stokes equations. The purpose of this study is to extend the capability of the dual-potential method to the computation of unsteady flows of viscous, compressible fluids.

In the dual-potential method, a flow field is characterized by nonprimitive variables — a scalar potential, a vector potential, vorticity, and dilatation — dependent variables that are not directly or easily measurable. The primitive (directly measurable) variables (pressure and velocity, for example) and the nonprimitive variables are mathematically derived from each other. In a dual-potential formulation of the Navier–Stokes equations, the differential equations for the primitive variables are replaced by the corresponding differential equations for the nonprimitive variables. Although the dual-potential Navier–Stokes equations are more numerous and complicated than are those of the primitive-variable method, a suitable dual-potential formulation can facilitate solution by numerical techniques, provided that adequate computing resources are available.

In the dual-potential formulation of this study, the velocity field is decomposed into an irrotational part that is expressed as the gradient of a scalar potential and a solenoidal part that is the curl of a vector potential, according to the Helmholtz decomposition theorem. The vorticity and the dilatation, which are used as dependent variables in the equations for the conservation of momentum, are easily obtained by taking second-order spatial derivatives of these potentials.

Because the resulting dual-potential Navier–Stokes equations are less closely coupled than are those of the primitive-variable formulation, the dual-potential approach accelerates convergence in iterative solution schemes. In this study, a time-accurate, iterative algorithm is used for the uncoupled solution of the equations. This formulation makes available several levels of approximation, including potential-flow, Euler, and full Navier–Stokes solutions. For some flows, computational efficiency can be enhanced by dropping the vorticity and/or the dilatation from the calculation in regions in which they are negligible. Also, efficient Poisson-equation-solving subalgorithms are available for

computating potentials.

The algorithm is applied to some two-dimensional test cases ranging from potential to full Navier–Stokes flows, and to some simple three-dimensional cases for an incompressible fluid. Among other things, these computations demonstrate the flexibility of the dual-potential formulation (ease of specialization to the various approximate solutions), and the accuracy with which it represents incompressible flows. It can handle both irrotational and rotational inlet boundary conditions easily. It is, however, somewhat limited in its ability to handle compressible, viscous flows with gradients of pressure. Consequently, further development will be necessary to obtain a trouble-free formulation for compressible flows.

This work was done by S. G. Gegg, and R. H. Pletcher of Iowa State University with J. L. Steger of **Ames Research Center**. *To obtain a copy of the report, "A Dual Potential Formulation of the Navier–Stokes Equations," Circle 10 on the TSP Request Card. ARC-12720*

Flow Over a Simplified-Rocket-Shaped Body

Measurements of pressure and visualizations of flow confirm a theory.

A report describes observations of the supersonic flow of air over a cylindrical body capped by a hemisphere at its head and flared to a cone at its tail end. This and related studies of three-dimensional separated and vortex-dominated flows over simple bodies are prompted by the need for greater aircraft control at high angles of attack.

A previous theoretical study of the flow over a hemisphere/cylinder had shown that local extrema in the distribution of pressure on the surface should correspond to each of the singular points in the flow pattern of oil released on the surface. Oil is used to help visualize the flow of air through the effects of skin friction. In particular, each node of attachment, node of separation (or focus), and saddle point in the pattern should coincide with a maximum, minimum, and saddle point, respectively, in the surface pressure distribution.

To test this theory, a hemisphere/cylinder/cone model was constructed, which was 16.8 in. (42.7 cm) long and 2.6 in. (6.6 cm) in hemispherical/cylindrical diameter, and mounted in a mach 1.2 free stream flow at angles of attack ranging from 0° to 27.5°. The body was instrumented with pressure transducers and switching valves to obtain measurements at 421 orifices distributed over its surface, and was rotated (under the assumption of symmetry) in 3° increments around its cylindrical axis to obtain a finely spaced pressure distribution consisting of 50,520 data points at each angle of attack. The oil used to visualize the flow was mixed with titanium oxide and fluorescent material to enhance visibility. When corrected for systematic errors and smoothed, the measured pressure distributions confirmed the predicted relationship between the singular points and the extrema of pressure.

This work was done by Lewis B. Schiff of **Ames Research Center** *and Andrew J. Meade, Jr., of the University of California at Berkeley. Further information may be found in AIAA paper 88A-10498, "Experimental Study of Three-Dimensional Separated Flow Surrounding a Hemisphere-Cylinder at Incidence."*

Copies may be purchased [prepayment required] from AIAA Technical Information Service Library, 555 West 57th Street, New York, New York 10019, Telephone No. (212) 247-6500.
ARC-12108

Simulation of Unsteady, Inviscid, Rotational, Transonic Flow

Two-dimensional Euler equations are solved in a finite-volume scheme.

A report describes a numerical simulation of two-dimensional, unsteady, inviscid

rotational, transonic flow about a rigid airfoil in such motions as pitching or plunging oscillations. The study demonstrates the potential utility of this type of computation in analyses of the aeroelasticity of airfoils.

The Euler equations of unsteady two-dimensional flow are put in integral form for solution by a finite-volume numerical integration scheme. The computational mesh is chosen to move with the airfoil, and the finite-volume formulation is established by use of spatial coordinates in a relative Cartesian frame fixed to the airfoil at a convenient point.

The solution procedure is based on an explicit Runge-Kutta time-stepping scheme in which spatial terms are centrally differenced and a combination of second and fourth differences in the flow variables are used to form the numerical-dissipation terms to stabilize the solution against spurious numerical oscillations. Solutions for steady-state flow are used as the initial conditions for calculations of unsteady flow. Nonreflective boundary conditions are imposed at the far-field boundaries.

Simulations are conducted for an airfoil oscillating in pitch in a transonic flow, an airfoil plunging in transonic flow, and an airfoil in oscillating translation (or stationary in an oscillating free stream). Simulations of the indicial responses of airfoils to impulsive plunging and to steep changes in the angle of attack in transonic flow are also described.

The results of the simulations are presented in the form of graphs of aerodynamic coefficients versus position, angle of attack, and phase angle; shock loci; pictures of supersonic pockets at various instants; pressure, mach-number, and entropy-contour plots; and other data. The results are found to agree well with such experimental data as are available and applicable.

This work was done by Murali Damodaran of **Ames Research Center**. *Further information may be found in AIAA paper 88A-22006, "Finite Volume Computation of Unsteady Inviscid Rotational Transonic Flows Past Airfoils in Rigid Body Motion."*

Copies may be purchased [prepayment required] from AIAA Technical Information Services Library, 555 West 57th Street, New York, New York 10019, Telephone No. (212) 247-6500. ARC-12113

Measurements of Turbulent Flow About an Airfoil

Laser Doppler velocimetry appears to be more reliable than hot-wire anemometry.

The wind-tunnel flow velocities measured by a laser Doppler velocimeter (LDV) are closer to calculated velocities than are those measured by a hot-wire anemometer, according to a report. The LDV was used to measure the flow fields around an airfoil equipped with a deflected spoiler. A two-component LDV system measured the mean and fluctuating velocities around an airfoil in a 25- by 11-cm wind tunnel. The green and the blue components of the light from a 5-watt argon-ion laser were separated and directed to the tunnel. Latex particles in the airstream scattered the laser light. A photomultiplier received the scattered light intercepted by a lens system; the pulses put out by the photomultiplier were counted and fed to a minicomputer for recording and analysis.

The measurements were made at a free-stream velocity of 70 m/s, corresponding to a Reynolds number of 740,000. The flow field was measured at about 20 points across the chord for each of 18 points along the chord. About 1,000 instantaneous values of velocity were measured at each point. From the data, longitudinal and transverse velocities and turbulent shear stresses, all averaged over time, were calculated and plotted as functions of position.

The flow field was simulated numerically by a two-dimensional vortex-tracing method in which the airfoil and spoiler were represented by vortex panels and the wake was represented by discrete point vortexes with viscous cores. The location of the point of separation of the flow from the bubble of the hinge of the spoiler was

determined by integral-boundary-layer calculations. Merging schemes were used to reduce the vortexes in the wake.

These measurements and calculations were compared with previous measurements by hot-wire anemometers and pitot-static tubes. The LDV values agreed most closely with the calculations. The authors conclude that conventional instruments like pitot tubes or hot-wire anemometers are not useful near the trailing edge of the airfoil, where highly-turbulent reverse flow occurs. The LDV, however, yields reliable data at the trailing edge as well as at other parts of the airfoil.

This work was done by S. Bodapati and M. J. Foreman of the U.S. Naval Postgraduate School and C. S. Lee of Stanford University for **Ames Research Center**. *Further information may be found in AIAA paper 87A-44955, "Flow-Field Measurements of an Airfoil with a Deflected Spoiler Using an LDV System."*

Copies may be purchased [prepayment required] from AIAA Technical Information Service Library, 555 West 57th Street, New York, New York 10019, Telephone No. (212) 247-6500.
ARC-12110

Computational Fluid Dynamics Now and in the Future

Computer simulations are augmenting and, in some cases, replacing experiments.

A technical memorandum reviews the state of the art of computational fluid dynamics (CFD) and predicts future developments and applications. The memorandum notes that CFD enables the study of the physics of flows not previously understood. CFD is now applied routinely to complicated flows and is starting to influence the design of aerospace vehicles. CFD is also used to design experiments; for example, it helps in placing surface and field probes, correcting measurements for laboratory-induced effects, extrapolating experimental results, and interpreting measurements.

Major elements of research in CFD include the following:
- Validation of computer codes: Advanced optical instrumentation is yielding accurate, high-resolution measurements for comparison with computed values to show that modern, complex computer codes for CFD are accurate.
- Hypersonic flow: CFD is essential to the development of the National Aerospace Plane because ground test facilities do not exist for the speeds and energies involved in flight at mach numbers up to 25. CFD promises answers to questions about real-gas chemistry, compressibility, boundary-layer transition, surface

heat transfer, and the structure of shock waves — all effects of particular importance in hypersonic flight.

- Physics of turbulence: The merging of experiments with CFD provides much more information about turbulence than can be gleaned from experiments alone, and thus leads to better turbulence models.
- Scientific visualization: Advanced computer workstations are used both to display and to analyze the results of numerical flow simulations. This helps scientists to develop solutions to flow problems and to understand the solutions more completely.

In the future, CFD will make it possible to study the unsteady flows that occur when high-performance aircraft fly at large angles of attack. It will predict the performance of aircraft near their performance limits. CFD will also combine subdisciplines of chemistry and physics; for example, it will couple finite-rate chemistry equations with the Navier–Stokes equations.

New developments in computer equipment and programs will help to advance CFD. For example, parallel processing promises to increase vastly the capability of CFD. Already, Navier–Stokes equations are being solved on a 16,000-processor computer. In addition, expert-system software will help scientists divide complicated flow regions into several zones, each of which can then be analyzed with a relatively simple grid. Eventually, artificial intelligence will be used to analyze flow patterns and identify those of greatest interest.

This work was done by Paul Kutler and Anthony R. Gross of **Ames Research Center**. *Further information may be found in NASA TM-100091 [N88-24579], "Progress and Future Directions in Computational Fluid Dynamics."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
ARC-12538

Flow-Control Devices for Inlets of Indraft Wind Tunnels

Effects on the nonuniformity of flow in test sections are discussed.

A report presents a theoretical and experimental study of the effects of antiturbulence flow-control devices in the inlet of an indraft (as opposed to closed-circuit) wind tunnel upon the nonuniformity of flow in the test section of the tunnel. The flow-control devices in question include vanes, screens, and honeycombs, and they are placed in the inlet upstream of the con-

tracting section of the tunnel that leads from the inlet to the test section.

This study was motivated primarily by the lack of understanding of the flow in the inlet as it passes through the antiturbulence devices. For a wind tunnel that has a large contraction ratio, this lack of understanding is not serious because the relatively low velocity of the flow through the antiturbulence treatment reduces the sensitivity of the flow to nonuniformity. Unfortunately, an inlet that has a large contraction ratio is often too expensive and too large to build, particularly when a large test section is desired. A large body of literature concerning the performance of various flow-control devices that reduce turbulence in test sections is available. However, the effect of these devices on test-section flow nonuniformity had not been studied previously. Such effects are particularly strong in tunnels with short, low-contraction-ratio contracting sections that could satisfy constraints of size and cost.

For the theoretical part of this study, the flow in the wind tunnel is approximated as two-dimensional, inviscid, and incompressible. The mathematical model of flow is based on the stream-function, vorticity formulation of the Euler equations. In this model, the screens are represented as actuator disks, across which the total pressure is discontinuous. This model is found to yield distributions of dynamic pressure in the test section that agree well with experimental distributions.

Computations with this model also yield insight into the dynamics of the overall flow field. In particular, it is found that the primary factor that determines the distribution of the flow passing through a screen is the turning of the flow by the screen when the flow strikes the screen along a direction other than perpendicular to the plane of the screen. The amount of turning is determined by the drop in pressure through the screen and the angle of onset of the flow passing through the screen.

Further analyses illustrate the effect of geometric variations on the relative uniformity or nonuniformity of flow in the test section. Although the distribution of flow in the test section in the presence of a given combination of inlet geometry and screens can be calculated accurately by use of the model, the design of a small inlet for uniform flow is still a formidable problem because of the strong interaction between the inlet geometry and the characteristics of the screen. In the exploration of a more straightforward design approach, a cascade of vanes was placed in the inlet to provide a more controllable mechanism for the redistribution of flow. By properly tailoring the angles of the individual vanes, one can produce uniform velocity in the test section. A method of analysis based on existing potential-flow methods and an empirical screen-pressure-drop calculation is developed to demonstrate the utility of the inlet cascade.

The accuracy of the computations is demonstrated by use of experimental data from tests of a two-dimensional indraft wind tunnel. The computations are in very good agreement with the data in all cases. An extension of the results for the inlet cascade to three dimensions is demonstrated, and a successful design for a wind tunnel is presented.

This work was done by James C. Ross of **Ames Research Center**. *Further information may be found in NASA TM-100050 [N90-21778], "Theoretical and Experimental Study of Flow-Control Devices for Inlets of Indraft Wind Tunnels."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
ARC-12738

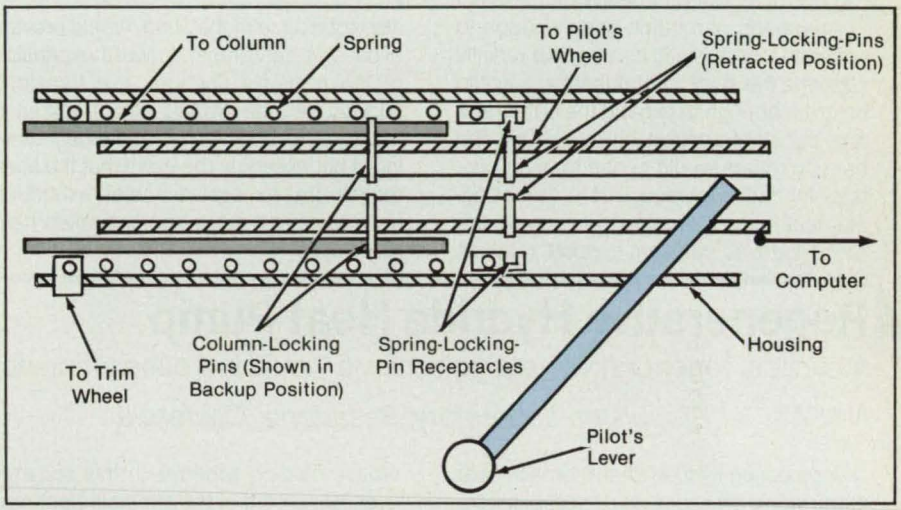
Machinery

Mechanical Backup for Fly-by-Wire Control System

A mechanical device eliminates the need for redundant fly-by-wire subsystems.

Langley Research Center, Hampton, Virginia

A mechanical backup device for a fly-by-wire aircraft-control system has been designed. In a fly-by-wire control system, the pilot's control wheel is mechanically disconnected from the aerodynamic control surfaces, so that the motions of the aerodynamic surfaces do not affect the position of the pilot's wheel as they do in conventional control systems. However, when the fly-by-wire control system malfunctions, a backup system is needed. In previous fly-by-wire control systems, backup has been supplied by redundant actuators, computers, electronics, and hydraulic systems. This redundancy increased the cost and made fly-by-wire control systems impractical for small, inexpensive, general-aviation airplanes. The new design provides mechanical backup that eliminates the need for this kind of redundancy.



Concentric Linkages Are Principal Elements in providing a conventional, reversible, mechanical backup for a fly-by-wire control system.

The main components are two linkages, as shown in the figure. One of the linkages is connected to the control column in a conventional, reversible control system. The other linkage slides inside the first linkage and is connected to the pilot's control wheel. In the normal fly-by-wire mode of operation, the two linkages slide independently of each other, and the position on the pilot's linkage is used as an input to the flight computer. The centering and feel of the pilot's control are provided by a spring attached to the pilot's linkage. The other end of the spring is connected to the pilot's trim wheel so that the pilot can position the wheel for hands-off operation.

When a malfunction occurs in the fly-by-wire control system, the pilot moves the control lever (similar to the gear-shift lever on a car) from the "engaged" to the "disengaged" position. A switch on the pilot's lever electrically disengages a conventional magnetic clutch between the actuator and the capstan, thereby mechanically disconnecting the aerodynamic surface from the actuator. The aerodynamic hinge moments then force the linkage connected to the column into a relatively fixed position.

In moving to the "disengaged" position, the lever also retracts the spring-locking pins (which previously connected the pilot's linkage to the centering spring) and spring-loads the column-locking pins in the extended direction. The pilot then moves the control wheel until the pins extend into the slot in the nearly stationary column linkage, thus securing the pilot's wheel to the column as shown in the figure. This mechanical arrangement provides a conventional, reversible control system for flying the airplane until a landing can be made.

The system described thus far is for the elevator-(pitch)-control loop. However, the design can easily be extended to include a fly-by-wire control for the aileron (roll). When this backup system is used, the need for multiple levels of redundancy in the fly-by-wire control system is eliminated. In addition to aircraft applications, this design can be used in control systems in which computer control is desirable but safety backup systems are required; for example, in boat rudders, engine controls in boats and automobiles, and controls in construction equipment.

This work was done by Eric C. Stewart of **Langley Research Center**. *For further information, Circle 152 on the TSP Request Card.*

LAR-13941

Hybrid Hydrostatic/Transient Roller Bearing Assembly

The rolling-element bearing would be centrifugally unloaded at high speed.

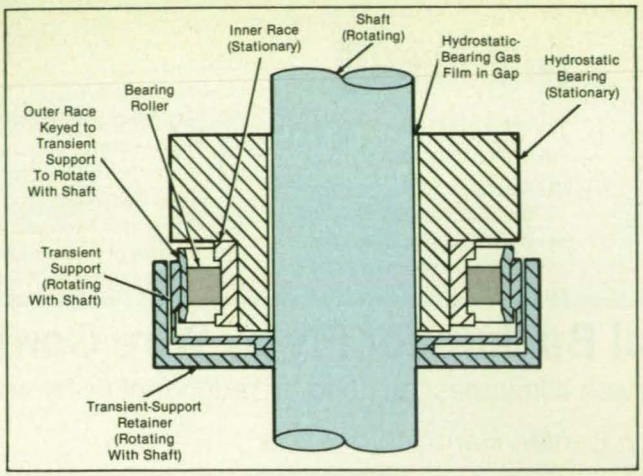
Marshall Space Flight Center, Alabama

A proposed bearing assembly for the shaft of a high-speed turbopump would include both hydrostatic and rolling-element bearings. As in other hybrid hydrostatic/rolling-element bearing assemblies, the rolling elements would support the shaft during relatively slow rotation at startup and shutdown, when the pump pressure is too low to provide a sufficiently stiff hydrostatic gas-film bearing. The proposed bearing assembly would differ from prior assemblies of this type in the manner of interaction between the rolling-element and hydrostatic bearings.

The bearing assembly (see figure) would include a stationary journal bearing that would serve as the hydrostatic bearing: the hydrostatic-bearing gas film would be

formed by designed leakage of the pressurized pumped gas along the gap between the shaft and the radially inner surface of this bearing. The inner race of the rolling-element bearing would be mounted on a radially outer surface of the hydrostatic bearing. The outer race of the rolling-element bearing would be keyed to a support (called the "transient" support because it would carry the load during the startup and shutdown transients) attached to the shaft so that both would rotate with the shaft. (Relative rotation between the transient support and the outer race must be prevented, especially if the pumped fluid is liquid oxygen, in which a high-speed rub could produce catastrophic results.)

At speeds of rotation great enough to generate a hydrostatic bearing that radially supports the shaft, centrifugal force would be great enough to expand the outer race and transient support so much that the bearing rollers would cease to be in contact with the inner race; that is, the rolling-element bearing would stop carrying the radial load. A transient-support retainer, also rotating with the shaft, would prevent excessive centrifugal outward expansion of the transient support. The transient-support retainer would also transmit a fractional load to the rolling-element bearing, if necessary, in the event that the shaft makes an excessive radial excursion (for example, if the pump is shaken hard sideways).



The **Rolling-Element Bearing** would be unloaded at high speed by centrifugal expansion of the outer race and transient retainer.

This work was done by John F. Justak of United Technologies Corp. for **Marshall Space Flight Center**. *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 16]. Refer to MFS-28491.

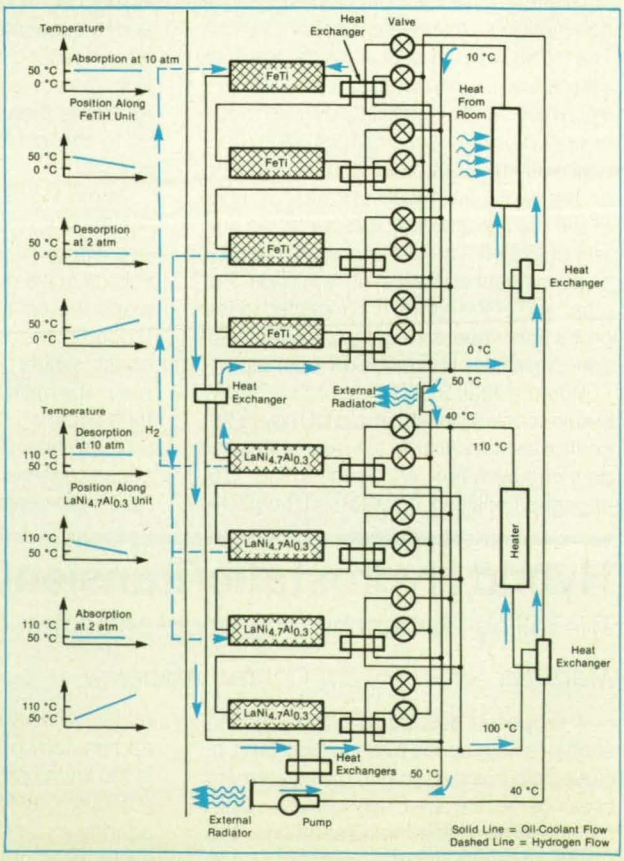
Regenerative Hydride Heat Pump

A cyclical regenerative heating scheme would increase efficiency.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed hydride chemisorption heat pump would be based on a cyclical regenerative heating scheme. In this scheme, over 90 percent of the sensible heat necessary to desorb hydrogen from each chemisorption unit during one phase of the cycle of operation would be supplied by recycling sensible heat from a similar chemisorption unit that was heated during the preceding phase. The portion of heat recycled in previous regenerative hydride heat pumps has been limited to

This **Hydride Heat Pump** would feature regenerative heating and a single circulation loop. Counterflow heat exchangers would accommodate the different temperatures of the FeTi and $LaNi_{4.7}Al_{0.3}$ subloops.



about 50 percent. The cooling coefficient of performance of the proposed heat pump is expected to be about 0.9, which is 40 to 50 percent greater than that of present hydride heat pumps. Another important advantage is that unlike the chlorofluorocarbon working fluids used in conventional mechanical heat pumps, the hydrogen working fluid does not damage the ozone layer of the atmosphere.

The proposed heat pump would include four FeTi and four $LaNi_{4.7}Al_{0.3}$ chemisorption units, which would operate in a four-phase cycle. In the air-conditioning version shown in the figure, a coolant, such as oil or water, would be circulated among the sorption units and associated heat exchangers, radiators, and other heat-transfer units by a pump and a system of cyclically switched valves. The main input power would be supplied in the form of heat from natural gas, the Sun, or an external source of waste heat, for example.

When the main input power was directed to one of the $LaNi_{4.7}Al_{0.3}$ units, it would raise the temperature of the unit to 110 °C, causing it to desorb hydrogen at a pressure of 10 atm (1 MPa). Simultaneously, hydrogen would be absorbed exothermally in one of the FeTi units, and the large heat of this reaction would be transferred to the environment via a radiator at a temperature of about 50 °C. When the $LaNi_{4.7}Al_{0.3}$ unit was cooled to 50 °C, it would reabsorb the hydrogen from the FeTi, causing the FeTi to cool a great deal — down to 10 °C at 2 atm (0.2 MPa) hydrogen pressure. More heat would then be absorbed from the room at 10 °C to release more hydrogen from the FeTi, thereby cooling the room.

The valve-switching sequence would be set so that each $LaNi_{4.7}Al_{0.3}$ and each FeTi unit would be at one of the four phases of the cycle. Thus, a cyclic wave of heating and cooling would travel around the fluid-flow circuit (upward along the sequence of sorption units in the figure), each unit being warmed up to its next hot phase or cooled down to its next cold phase partly by the flow of working fluid from the preceding hot or cold unit, respectively.

This work was done by Jack A. Jones of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 67 on the TSP Request Card.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

Edward Ansell
Director of Patents and Licensing
Mail Stop 305-6
California Institute of Technology
1201 East California Boulevard
Pasadena, CA 91125

Refer to NPO-18104, volume and number of this NASA Tech Briefs *issue, and the page number.*

Variable-Orifice Oxygen-Flow Regulator

The design minimizes erosion and accidental ignition caused by entrained metal particles.

Lyndon B. Johnson Space Center, Houston, Texas

A special valve is designed to regulate the flow of hot, high-pressure oxygen [maximum operating pressure and temperature 4,600 psia (31.7 MPa) and 530 °F (550 K), respectively]. In the basic design, it is actuated by a solenoid, switchable between a fully open and a partially open orifice position. Although the valve is designed for use with oxygen, it could also be used with a variety of liquids and gases.

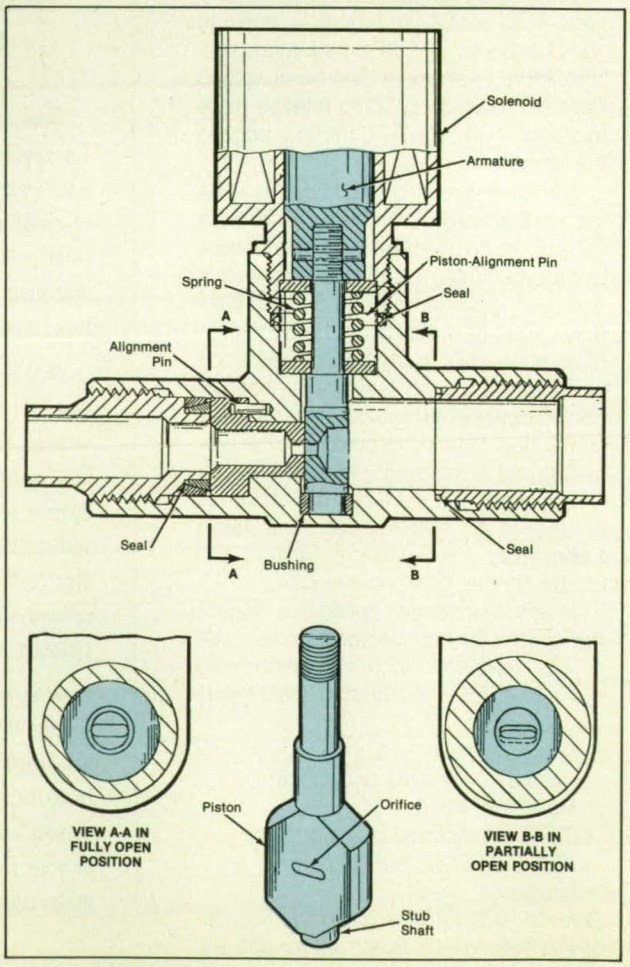
Among the principal considerations in the design are the need to minimize erosion of the interior surfaces of the valve by particles entrained in the flow of oxygen and the need to minimize the probability of ignition caused by impacts of the particles on the surfaces. Previous designs for flow-regulating valves have involved tortuous flow paths with excessive complication, tendency toward binding, and high susceptibility to ignition. In contrast, the present valve design features a straight-through flow path that is all but immune to the undesired effects, a mechanism that cleans itself of debris, simplicity (with consequent ease of fabrication and greater reliability), fewer and sturdier parts, and low impact velocities for entrained particles. In addition, the valve mechanism has low friction, and it switches rapidly between the two flow-regulating orifice positions.

The valve includes an orifice fixed in a housing and an orifice in a piston that slides in the housing against the fixed orifice (see figure). The piston is spring-loaded downward into the fully open position, in which the two orifices are aligned. When the solenoid is turned on, it pulls the piston upward into the partially open position, in which the two orifices are laterally misaligned, effectively reducing the cross section of the combined orifices and thereby impeding the flow.

Because a relatively short solenoid stroke is required, one can take advantage of a large solenoid force to assure rapid, trouble-free operation. The matching configurations of the fixed orifice and the movable orifice in the piston reduce undesired effects associated with erosion and with particle-impact ignitions at some impact angles of incidence. In alternative versions, the valve could be actuated by pneumatic, hydraulic, or centrifugal mechanisms, and there could be more than two flow-regulating orifice positions. In addition, the basic design concept encompasses such other fixed-orifice/piston-orifice configurations as circular for reduced disruption of flow, slotted for maximum metering effect in a small stroke, or triangular for variable metering per unit increment of stroke.

This work was done by Rollin C. Christianson of Lockheed Engineering & Sciences Co. for **Johnson Space Center**. *For further information, Circle 6 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center [see page 16]. Refer to MSC-21549.



The **Variable-Orifice Flow-Control Valve** is switchable between fully and partially opened positions. The straight-through flow path minimizes high-speed impacts of entrained particles, reducing erosion and accidental ignition.

Computer Program Aids Design of Impeller Blades

An iterative algorithm yields hydrodynamically optimal contours.

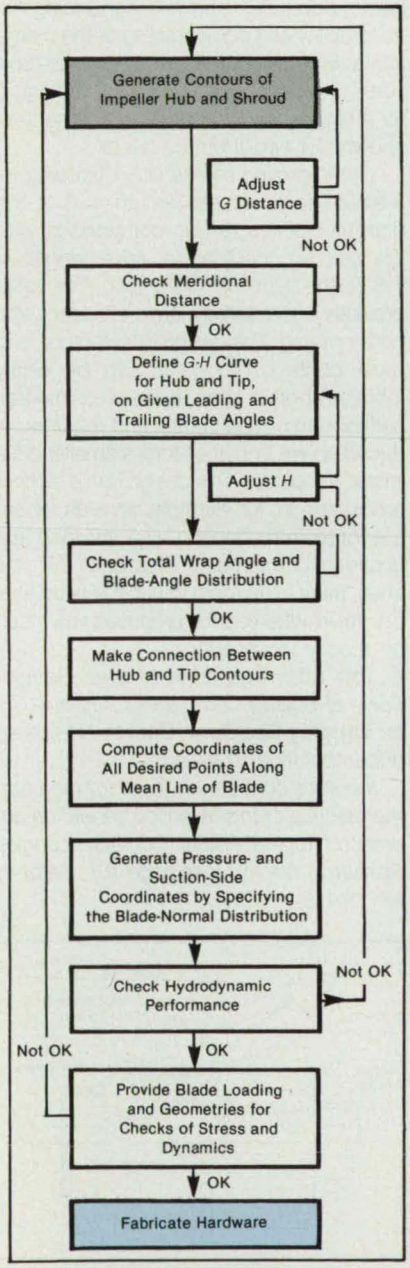
Marshall Space Flight Center, Alabama

Impeller blades for centrifugal turbopumps can be designed quickly with the help of a computer program. The program lays out a blade in the *G*–*H* plane; this ensures a smooth blade-angle distribution because the slope of a *G*–*H* curve is the blade angle. (*G* is the meridional distance, and *H* is the circumferential distance in a plane perpendicular to the axis of rotation.)

The program (see figure) is written so that the contour of the blade between the hub and the tip of the impeller is described by a polynomial. This not only guarantees tangency of the contour at the inlet and outlet but also guarantees a smooth transition from the inlet to the outlet.

With the program, an engineer can check the smoothness of the blade angle and the total wrap angle. The engineer can also take advantage of the fact that there exists a range of *H* for which the hub and tip have about the same total wrap angle — a condition that enhances the performance of the impeller.

Because the program defines blade geometries algebraically, digitized and graphical approximations are avoided. Moreover, the program can be executed rapidly, so that an engineer can review many alternatives at relatively low cost before selecting a final design. Although the program was written for centrifugal turbomachinery,



A Program Generates Blade Contours and continually subjects them to evaluation. It checks the physical parameters to ensure that they are compatible with the required performance and recycles a design if criteria are not met.

it can readily be adapted to such axial pump components as inducer blades and stator vanes.

This work was done by Wei-Chung Chen and John V. Galazin of Rockwell International Corp. for **Marshall Space Flight Center**. *For further information, Circle 99 on the TSP Request Card.*
MFS-29783

Improved Merge Valve

A circumferential design combines compactness and efficiency.

Langley Research Center, Hampton, Virginia

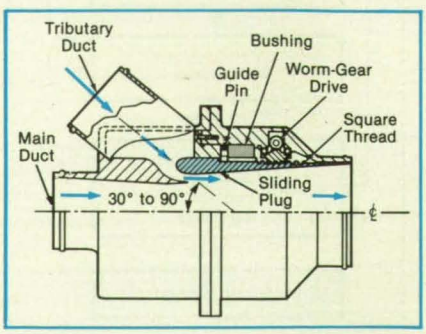
Typical merge valves in current use are of the flapper-valve variety. The flapper-valve design is proven and widely accepted. However, an alternate concept for the design of merge valves is proposed for use in situations in which extreme compactness is required. With this new valve, the flow in the tributary duct is introduced along the circumference of the primary duct through a variable throat nozzle.

The circumferential merge valve is shown in the figure. The flow through the tributary duct is controlled by the variable throat nozzle, which is actuated by an integral worm-gear/screw-drive mechanism. By this arrangement, the flow in the main duct encounters minimum disturbance, and better mixing is achieved. The angle of entry of the tributary flow can be chosen between about 30° and 90°, enhancing the adaptability and compactness of the merge valve. Two conceptual arrangements have been proposed: one like that of the figure for a single-tributary duct and another (not shown) for two tributary ducts.

The improved merge valve features increased compactness (length = 3 × the diameter of the exit) in comparison with the well-designed flapper valve (length = 7.5 × the diameter of the exit). The valve provides better aerodynamic efficiency and better mixing. The design is leak-proof, and most of its components can be easily fabricated on a lathe. It features integral, self-locking nozzle control and requires reduced power, and, therefore, a smaller drive motor, to operate. This design has a distinct advantage in, for example, an area where the three main ducts merge into one just upstream of a turbocompressor. In this situation, there is no room to put in a good flapper valve, whereas the proposed valve can be readily incorporated.

This work was done by Dez George-Falvy of Boeing Commercial Airplane Co. for **Langley Research Center**. *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Langley Research Center [see page 16]. Refer to LAR-14176.



In this **Remotely Controlled Valve**, the flow in a tributary duct along the circumference of a primary duct is merged with the flow in the primary duct. The flow in the tributary duct is regulated by a variable throat nozzle driven by a worm gear.

Books and Reports

These reports, studies, handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Unified Formulation of Dynamics of Robot Arms

Algorithms and the interrelations among them are clarified.

A report presents an analysis of a variety of algorithms that have been developed in recent years to solve the equations of motion of multiple-rigid-link robot arms. Most of the discussion is about the forward-dynamics problem (given the forces and torques on the joints between the links, find the linear and angular accelerations of the links), as distinguished from the inverse-dynamics problem (find the forces and torques that produce the given accelerations). Rather than reproduce the original rationale that led to the development of the various forward-dynamics algorithms, the techniques of spatial-operator algebra are used to derive the algorithms concisely and study the relationships among them.

The spatial-operator algebra is a theoretical framework for the analysis of the dynamics of multibody systems. Spatial operators and the identities among them provide concise descriptions of the equations of motion and the means to study the structures of those equations and to derive algorithms to solve them. In this study, a coordinate-free notation is used to decouple the formulation of algorithms from the computational implementation of algorithms. This coordinate-free formulation makes it possible to study the structures of the various forward-dynamics algorithms.

The report contains eight sections and an appendix; the major developments are presented in sections 2 through 6. In section 2, the equations of motion are developed and the coordinate-free notation is introduced in the process. The spatial operators are also introduced, and the equations of motion are recast in a concise form.

Each algorithm is characterized by, among other things, a semiquantitative measure of its complexity, $O(N^k)$, meaning that it calls for a number of arithmetical operations proportional to a number of the order of N^k, where N is the number of degrees of freedom in the particular dynamical problem and $k = 1, 2,$ or 3. Section 3 of the report discusses the class of $O(N^3)$ forward-dynamics algorithms, which are based on the explicit computation of the mass matrix, M, followed by the $O(N^3)$ process of solving the linear matrix equation $M\dot{\beta} = \hat{T}$, where $\dot{\beta}$ is a generalized joint-acceleration vector and $\hat{T}$ is a generalized, bias-free vector of forces and torques on joints. It is shown that among three $O(N^3)$ algorithms, the one based on the composite-rigid-body inertias takes the most advantage of the structure of the equations of motion and is the most efficient.

Section 4 discusses four $O(N^2)$ forward-dynamics algorithms: two based on the conjugate-gradient method, the other two based on repeated solutions of triangularized systems of equations. The latter two are shown to be equivalent.

Section 5 presents a derivation of the articulated-body algorithm, which is a generalized $O(N)$ forward-dynamics algorithm. This algorithm is used to discuss and compare a number of previously developed $O(N)$ forward-dynamics algorithms, which are shown to be essentially the same algorithm with minor differences.

Section 6 presents a derivation of operator factorizations and inversion of the mass matrix. It indicates the connection with the factorizations used in Kalman-filter theory, suggesting that Kalman analysis is applicable to multibody-dynamical problems. It also shows that the $O(N)$ articulated-body algorithm follows as a direct consequence of the operator factorizations.

This work was done by Abhinandan Jain of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report "Unified Formulation of Dynamics for Serial Rigid Multibody Systems," Circle 132 on the TSP Request Card.*
NPO-18040

Evaluation of Performance of a Telerobot

Various tasks were performed with and without force feedback.

A paper presents an evaluation of the performance of a six-axis telerobot system with shared control and advanced modes of force feedback. The evaluation is based on manipulation experiments in which the system was operated in two modes: with position control only and with position control and force feedback. To establish an additional basis for comparison, tests were also conducted in a third mode in which technicians performed the same manipu-

lations with their hands. The experiments consisted of the following four tasks:

- Exchange the positions of two differently shaped blocks attached to a task board with Velcro hook-and-pile material. The objective is to attach the blocks securely while minimizing unnecessary force.
- Insert pegs in designated holes in a square matrix of nine holes. The holes in each succeeding row present a larger clearance, while those in each succeeding column present a different chamfer.
- Mate and unmate 3 standard electrical connectors — a 3-prong chassis power-cord connector, a 25-pin signal connector, and a 1/4-in. (6.35-mm) telephone plug.
- Unlock, unmate, mate, and lock a bayonet-style electrical connector.

The performance of the system in each of the tasks was evaluated on the basis of the forces, torques, and time required. The performance clearly improved as the level of sensitivity progressed from position control to position control with force reflection to barehanded operation: the average time to complete the first three tasks was 92 s with position control only, 63 s with position control and force feedback, and only 14 s for the bare-handed technicians. The average number of errors in the completion of the first three tasks was about three with position control only, about one with position control and force feedback, and zero for the barehanded operators. The sum of squared forces, a measure of the force or torque required for a task, fell even more dramatically in the progression through the three modes. (The fourth task was not included in the calculations because it took much longer than the other tasks did and often could not be completed because of its difficulty.)

Overall, the study found that force feedback reduced the average time required to complete a task by about 30 percent. It reduced sum of squared forces by a factor of 7 and errors by 63 percent.

This work was done by Blake Hannaford and Laurie A. Wood of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Performance Evaluation of a 6 Axis High Fidelity Generalized Force Reflecting Teleoperator," Circle 62 on the TSP Request Card.*
NPO-17924

Langley Aircraft Landing Dynamics Facility

Aircraft landing-gear systems are tested on actual runways at operational conditions.

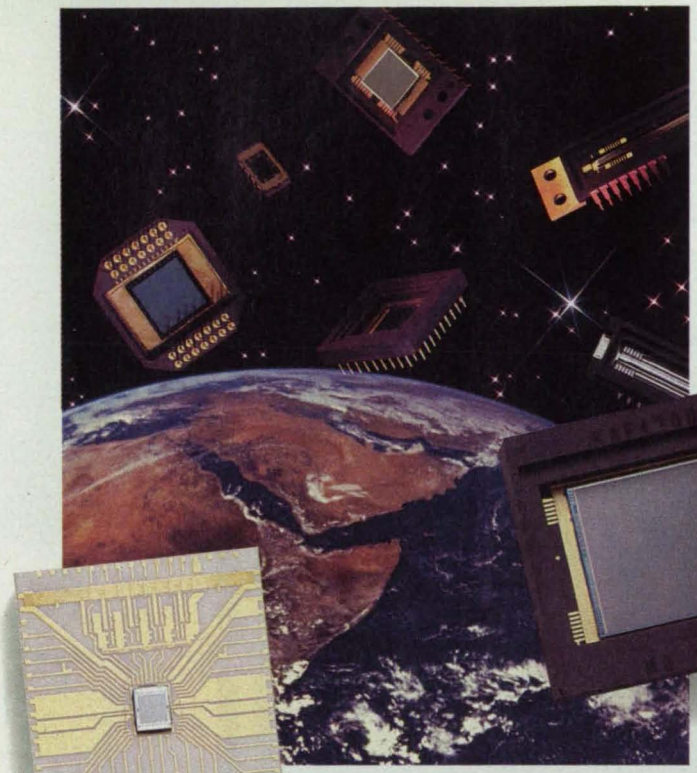
A NASA Reference Publication reports on NASA Langley Research Center's recent upgrading of the Landing Loads Track (LLT) to improve the capability of low-cost testing of conventional and advanced landing-gear systems. The unique feature of the Langley Aircraft Landing Dynamics Facility (ALDF) is the ability to test aircraft landing-gear systems on actual runway surfaces at operational ground speeds and loading conditions. A historical overview of the original LLT is given, followed by detailed description of systems and operational capabilities of the new ALDF.

The ALDF began operation in 1985. It has the capability of testing full-size aircraft landing-gear systems under closely controlled simulated takeoff and landing conditions on actual runway surfaces. Testing landing-gear systems on the ALDF is advantageous over flight testing for such reasons as safety, economy, control of parameters, and versatility. Virtually any aircraft landing-gear system or subsystem can be accommodated on the ALDF test carriage. Novel landing-gear concepts can also be investigated, and the versatility of the facility enables testing on a variety of runway surfaces under many different simulated weather conditions. The paper gives a brief historical overview of the LLT, the facility that preceded the ALDF, and discusses how the older facility was upgraded to the present ALDF configuration. It describes the main features of the ALDF, including the high-pressure propulsion system, the test carriage, the track, the arresting-gear system, and the data-acquisition system.

This unique facility is capable of testing various types of landing-gear systems at speeds up to 220 kt (113 m/s) on a variety of runway surfaces, under all types of weather conditions. The facility has a track 2,800 ft (853 m) long with a test section 1,800 ft (549 m) long, which allows 5 s of test time at maximum speed. Test articles can be subjected to vertical loads up to 65,000 lb (2.9×10^5 N) or sink rates of 20 ft/s (6 m/s). This facility significantly increases the capability to conduct low-cost tests of conventional and advanced aircraft landing-gear systems. The capabilities facilitate testing at speeds and sizes pertinent to large transport aircraft, fighter aircraft, and the Space Shuttle Orbiter.

This work was done by Pamela A. Davis, Sandy M. Stubbs, and John A. Tanner of **Langley Research Center**. *Further information may be found in NASA RP-1189 [N87-29544], "Langley Aircraft Landing Dynamics Facility."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
LAR-14038



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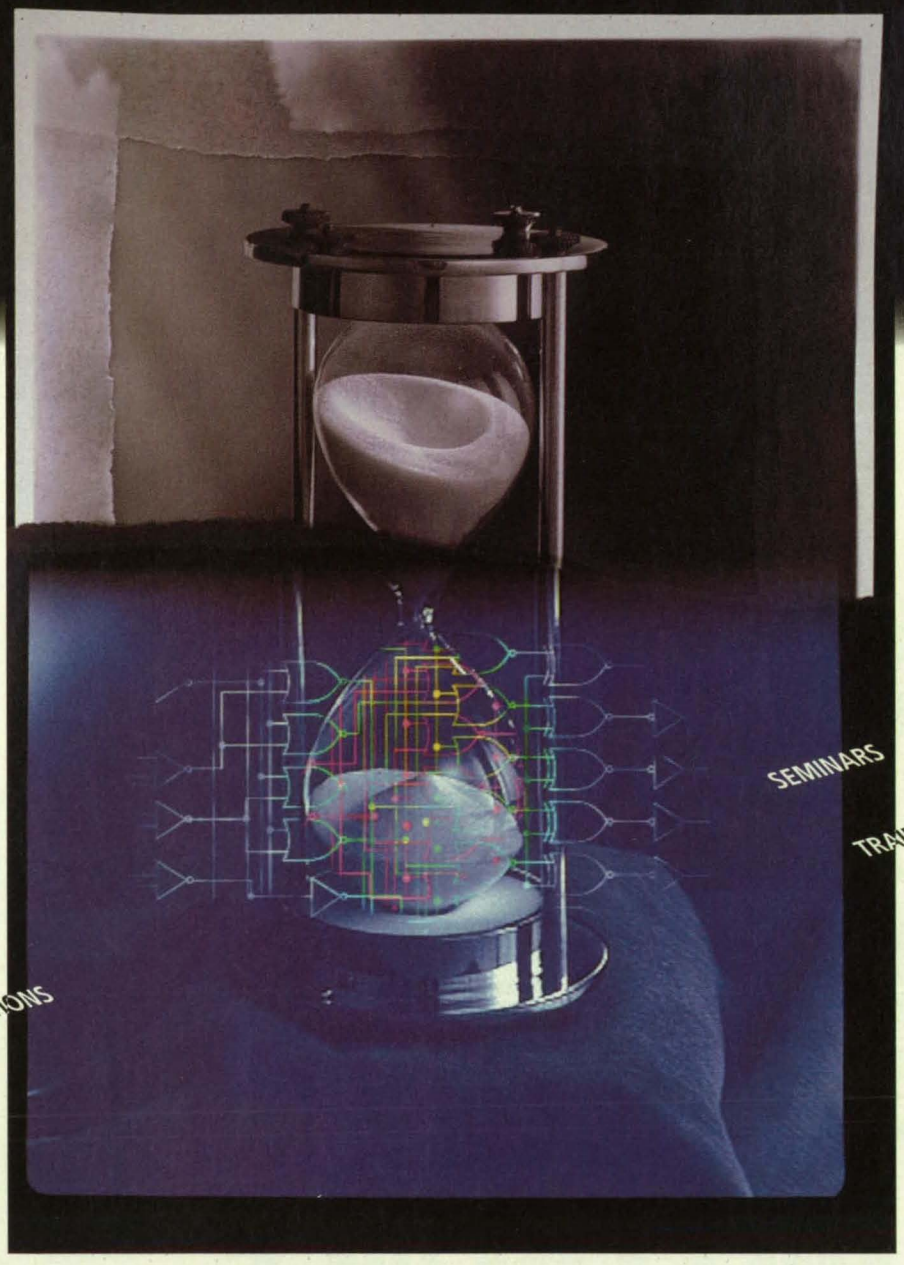

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Fabrication Technology

Hardware, Techniques, and Processes

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Steel Collet for Welding Electrodes

A simple holder resists deformation and ensures reliable arc starting.

Marshall Space Flight Center, Alabama

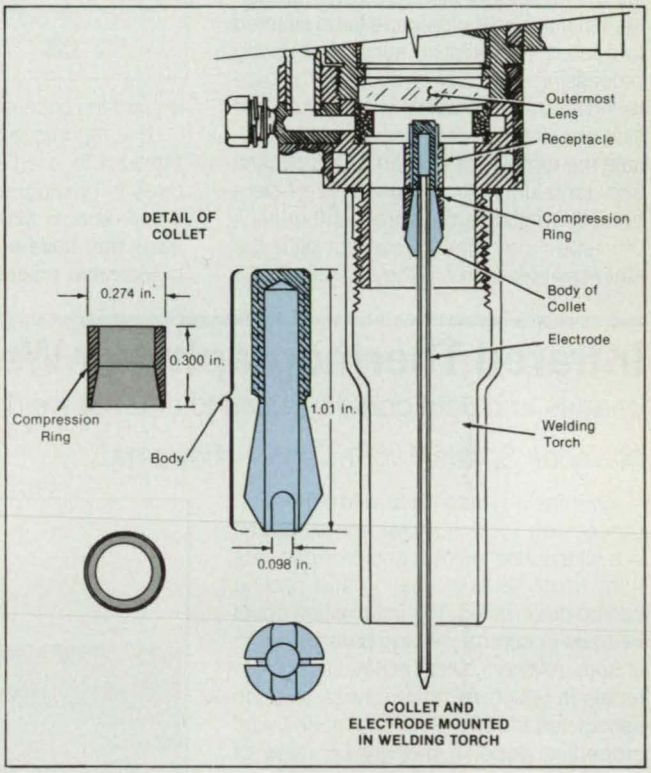
An improved steel collet holds an electrode for tungsten inert-gas welding but allows quick and easy replacement. It also ensures reliable arc starting.

The collet consists of a body with tapered and threaded sections and a compression ring (see figure). The electrode is inserted in a blind hole in the body. The ring is slipped onto the tapered section of the body. When the threaded end of the body is screwed into a receptacle in the welding torch, the ring compresses the body so that it clamps the electrode. The assembly can be removed from the torch simply by unscrewing the body.

The steel collet replaces a copper collet that had several deficiencies, one of which was that starting an arc usually required several attempts. The tool steel and stainless steel used in the new collet have thermal conductivities lower than that of copper; this promotes the emission of electrons and makes starting easier. With the new collet, as a result, an arc always starts on the first attempt. Moreover, the steels are not as vulnerable to galling and deformation as copper is.

The installation and removal of the electrode were more difficult with the old collet. The technician had to turn a nut on a left-handed thread on the collet to clamp the electrode, then screw the right-handed thread on the end of the collet into the torch. Now, only one threading operation is needed.

In the old collet, the electrode was held in a through hole. The new collet holds it in a blind hole. Thus, the inner end of the electrode cannot slip through the collet and damage the lenses in a coaxial-vision torch.



The **Slip-On Compression Ring** compresses the tapered section of the body of the collet around the inner end of the welding electrode. The collet is mounted in a receptacle below a stack of lenses and filters in a coaxial-vision welding torch. The blind hole in the collet protects the outermost lens from damage by the electrode.

This work was done by Jeffrey L. Gilbert, David A. Gutow, Richard K. Burley, and Irving Fogul of Rockwell International Corp. for **Marshall Space Flight Center**. *For further information, Circle 98 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 16]. Refer to MFS-29762.

Superplastic Titanium Tube Applies Pressure for Sintering

Even, controllable pressure is applied over the entire surface to be sintered.

Langley Research Center, Hampton, Virginia

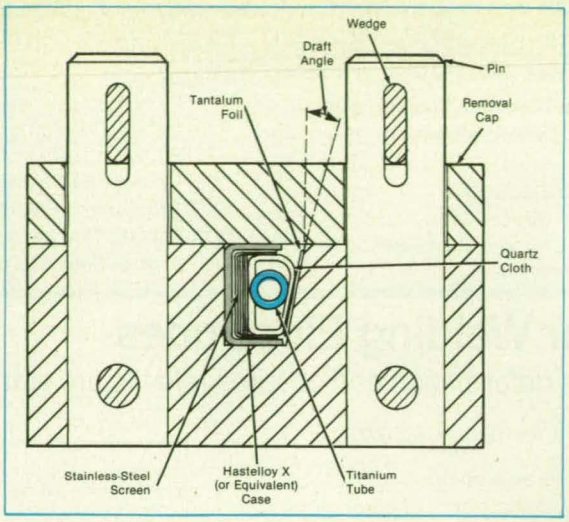
The fabrication of a high-temperature liquid-metal heat pipe requires the sintering of a delicate screen made of stainless steel and a case made of Hastelloy X (or equivalent) Ni/Fe/Cr/Mo/C alloy. To obtain a good metallic bond between the screen and the case, low pressure must be applied evenly at a temperature of more than 2,000 °F (≥ 1,100 °C) over the entire surface to be sintered, and the parts must be kept clean throughout the thermal cycle. Such established techniques as "canning," which involve the use of welded metal containers or ceramic beads, are time consuming and/or seldom produce the desired uniformity. In a newly developed technique, a titanium vessel is filled with a gas to exert the pressure necessary for sintering.

Some titanium alloys, when heated to approximately 1,700 °F (about 930 °C) become superplastic; that is, they become superductile and offer little resistance to forming. A process that takes advantage of superplasticity is called "superplastic forming" (SPF). Because a titanium pressure vessel can be made by SPF at a temperature lower than that required to sinter the parts of the heat pipe, such a vessel can be preformed to the precise shape of a part to be sintered. Also, because the SPF temperature for the pressure vessel is less than the sintering temperature for the heat pipe, a pressure greater than that to be used in sintering the parts of the heat

pipe can be used to form the titanium pressure vessel.

After forming the titanium pressure vessel, the pressure can be decreased to the desired sintering pressure and held until the sintering temperature is reached. The pressure in the gas in the vessel transmits the force evenly over distance and through small cross sections with negligible losses. This technique ensures even, controllable pressure over the entire surface to be sintered, throughout the sintering cycle.

The parts to be processed are contained in a tool (see figure) capable of withstanding the necessary pressures and temperatures. If the heat-pipe parts to be sintered to each other must be supported during processing, the tool is designed to surround the parts completely. A taper on one side provides the draft necessary to facilitate the removal of the parts. Quartz cloth and tantalum foil are used to prevent eutectic melting and to prevent the titanium tube from making contact with the stainless-steel screen, the Hastelloy X (or equivalent) case, or the stainless-steel tool.



A **Titanium Tube Heated to Superplasticity** is pressurized from within to form it into the shape of the screen and case to be sintered to each other.

This technique that involves the SPF of titanium to exert even pressure can be used in brazing, sintering, and hot forming. It should simplify the fabrication of parts that have complicated shapes and could have potential for a variety of applications, including the fabrication of heat pipes for high-performance vehicles.

This work was done by Allen H. Mueller and Thomas R. Pleimann of McDonnell Douglas Corp. for **Langley Research Center**. *For further information, Circle 94 on the TSP Request Card.* *LAR-14018*

Infrared Thermography for Welding

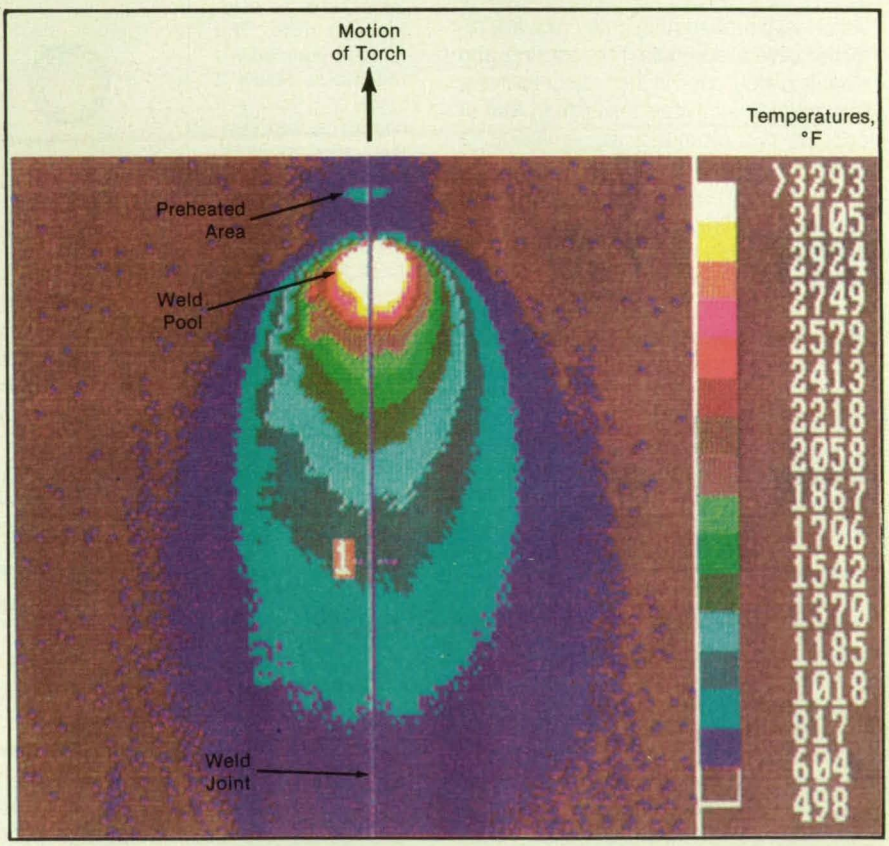
Images and data could be used to analyze welds and control welding parameters.

Marshall Space Flight Center, Alabama

An infrared imaging and image-data-processing system shows temperatures of a joint during welding and provides data from which rates of heating and cooling can be determined. The information could be used to control welding parameters to ensure reliable joints, especially in materials in which microstructures and the associated metallurgical and mechanical properties depend strongly on rates of heating and cooling. Such materials include nickel alloys, titanium aluminide, and metal-matrix composites.

The system, based on a high-resolution infrared scanner, displays a real-time image of the weld in which bands of equal temperature are represented by colors (see figure). Such defects as impurities, gaps, surface irregularities, porosity, and tungsten inclusions are evident from the gradients of temperature they produce.

In addition to displaying images, the system extracts temperature data from the image. In principle, these data could be processed to determine the degree of penetration of the weld and the effects of back-side cooling. The system could also be used to build a data base of welding parameters for various materials. The system is applicable to a variety of processes, including tungsten/inert-gas welding; plasma, laser, and resistance welding; cutting; and brazing.



The **False-Color Scale in an Image of a Weld** shows the distribution of temperatures. The bands of color show preheating of the area immediately ahead of the torch, the weld pool, and the cooling of the area behind the torch.

This work was done by Jeffrey L. Gilbert, Brian D. Lucky, Lyle B. Spiegel, and Russell M. Hudyma of Rockwell International Corp. for **Marshall Space Flight Center**. *For further information, Circle 7 on the TSP Request Card.*
MFS-29746

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Calibration Check for Programmed Welding Robot

A fast and simple procedure verifies the torch setup.

Marshall Space Flight Center, Alabama

A preweld calibration check helps to ensure that a welding torch on a computer-controlled welding robot has been mounted properly, that the right gas cup has been selected, and that the length of extension of the electrode has been adjusted correctly. The calibration check is performed by the operator just before the dry run for each set of parts to be welded. The procedure takes only 2 to 3 minutes and enables the correction of errors before parts or equipment are damaged.

Positioning errors usually do not occur when the operator "teaches" the path manually to the robot; the operator merely adjusts the path to suit the dimensions of the parts and the welding equipment. With programmed paths, however, normal variability in dimensions (and mistakes in programming) can result in collisions, with consequent damage to the workpiece, equipment, or both.

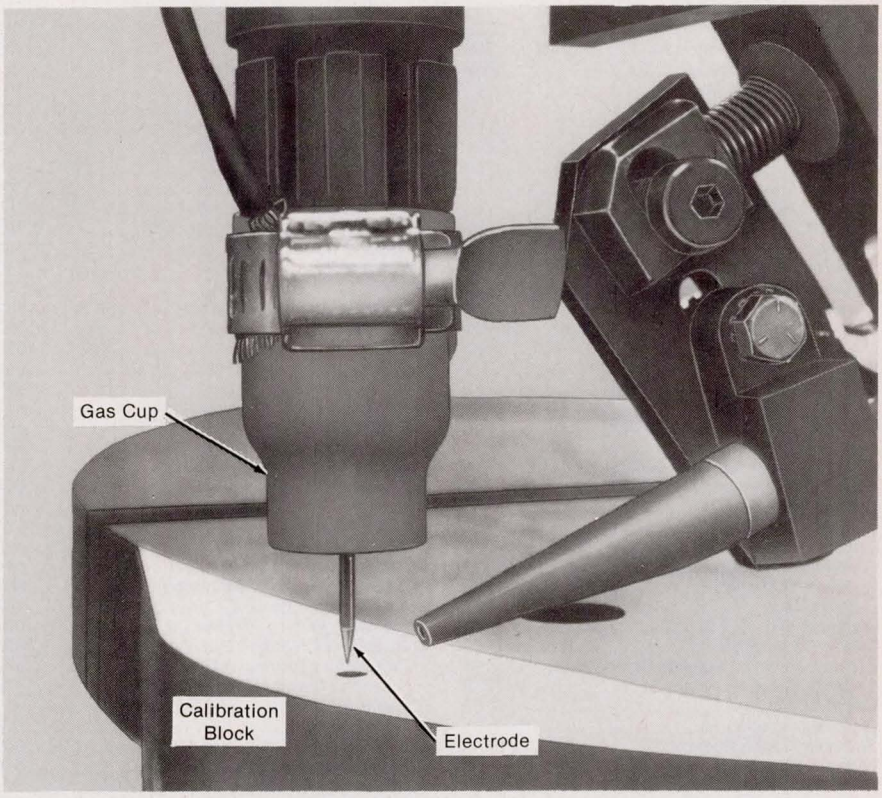
The welding engineer programs a weld by entering a variety of parameters into a data base, including such specifications as the type and number of the torch, the length of extension of the electrode, and the size and type of the gas cup. From this information, the computer simulates the welding procedure and displays it for the engineer on a video monitor. The engineer examines the simulated path for collisions and possible overtravel at the robot joints and makes whatever corrections are needed.

When the weld path satisfies the engineer, the computer generates weld commands and transfers them to the robot work cell. There, they wait in a queue until the parts are ready to be welded. When the parts are ready, the operator so informs the computer, which then displays detailed instructions to guide the operator through the weld. The operator sets up the robot manually by selecting the tooling, mounting the torch, and adjusting the gas parameters according to the displayed instructions.

After completing the manual setup, but before mounting the parts to be welded and the tooling, the operator performs the calibration check, which consists of the following steps:

1. Position the torch at a convenient location to check the type of gas cup, and set the length of extension of the electrode with the aid of a step block.
2. Move the torch to a point 12 in. (30.5 cm) above a calibration fixture—a small aluminum bracket with a hole ¼ in. (6.35 mm) in diameter mounted on the side of the welding table. Here, the operator can detect major errors in the torch setup.
3. Move the tip of the electrode to a point 4 in. (10.2 cm) above the calibration fixture. A quick measurement here indicates improper torch mounting without danger of damaging the torch.
4. Move the tip closer, to a point 1 in. (2.5 cm) above the fixture, and check the vertical distance with a step block.
5. Using the welding pendant (a manual control device), move the torch downward to verify that the electrode is aligned with the hole (see figure).

At any point in this procedure, the operator can correct the torch setup. When all is ready, the operator continues with a dry run and the actual welding.



The **Last Step in the Calibration Check** is to move the torch close to the hole in the calibration block to ensure proper alignment. After this, the operator can proceed with minimal risk of a collision between the robot and the parts to be welded.

This work was done by Karen E. Sliwinski, Ronald R. Anderson, and Mark R. Osterloh of Rockwell International Corp. for **Marshall Space Flight Center**. *For further information, Circle 96 on the TSP Request Card.*

MFS-29720

Making Thin Laminae of Frozen Alloy Slurries

These laminae, interspersed with fiber mats, can be used to make metal/fiber composites.

Langley Research Center, Hampton, Virginia

There is interest in consolidating metal-matrix/ceramic-fiber composite materials in thin layers. This would involve the lamination of very thin metal layers between layers of fibers, within each of which the fibers would be parallel. The first choice for the metal layers would be thin foils, but some of the brittle intermetallic alloys (e.g., titanium aluminides) that are of interest for this purpose are not now available as foils, while such techniques as plasma spraying and spraying or coating with polymer binders raise concern regarding contamination. A new technique that involves the use of sheets of frozen alloy powder over-

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Corning Inc. ... 772
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Crystal Image Technologies ... 770
Cybernet Systems ... 768
Datatape Inc. ... 767
Diamonex Inc. ... 766
Digiray Corporation ... 765
Earth Observation Satellite Company ... 764
Eastman Kodak Company ... 763
Echo Data Inc. ... 762
Electronic Imagery Inc. ... 761
European Space Agency ... 760
Federal Laboratory Consortium ... 759
Fermi National Accelerator Lab ... 758
FLIR Systems Inc. ... 757
Georgia Power Company ... 756
Goddard Space Flight Center ... 755
Hardigg Industries ... 754
Helicoflex Company ... 753
Hemco Corporation ... 752
Hewlett-Packard Company ... 751
Hi-Techniques ... 750
Hitachi Denshi America, Ltd. ... 749
Horstmann Software Design Corporation ... 748
Hughes Research Laboratories ... 747
Idaho National Engineering Laboratory ... 746
Information Handling Services ... 745
Inframetrics Inc. ... 744
Integral Systems Inc. ... 743
Integrated Engineering Software ... 742
Integrated Systems Inc. ... 741
Inventive Machine Laboratory ... 740
James Grunder & Associates ... 739
Jet Propulsion Laboratory ... 738
Johnson Space Center ... 736
JP Technologies Inc. ... 735
Keane Controls Corporation ... 734
Kennedy Space Center ... 733
Kevex X-Ray ... 732
Knowledge Express ... 731
Langley Research Center ... 730
Lawrence Livermore National Laboratory ... 729
Leep Systems ... 728
Lewis Research Center ... 727
Lockheed Missiles & Space Company ... 726
Loma Linda University Medical Center ... 725
Los Alamos National Laboratory ... 724
Marshall Space Flight Center ... 723
Martin Marietta Energy Systems ... 722
Martin Marietta Manned Space Systems ... 721
Martin Marietta Paducah Gas Diffusion ... 720
Mathworks Inc. ... 719
McClellan Air Force Base ... 718
MCNC, Center for Microelectronics ... 717
Meridian Laboratory Inc. ... 716
Metalworking Technology Inc. ... 715
Mikron Instrument Company ... 714
Morgantown Energy Technology Center ... 713
NASA ... 712
NASA Centers for the Commercial Development of Space ... 710
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NASA SBIR Program ... 708
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National Center for Manufacturing Sciences ... 706
National Center for Research Resources ... 705
National Institute of Standards and Technology ... 711
National Institutes of Health ... 704
National Instruments Corp. ... 703
National Renewable Energy Lab ... 702
National Science Foundation ... 701
National Space Society ... 700
Naval Air Warfare Center ... 699
Naval Research Laboratory ... 698
NERAC Inc. ... 697
NIAC ... 696
Novespace ... 694
NTBM Research Center ... 693
Numerical Algorithms Group ... 692
NYMA Inc. ... 691
Ohio Aerospace Institute ... 690
Olympus Corporation ... 689
Oneida Research Services Inc. ... 688
Optical Society of America ... 687
Oracle Corporation ... 686
Pacific Northwest Laboratory ... 685
Patton & Patton Software ... 684
Pittsburgh Energy Technology Center ... 683
PMS Electro-Optics ... 682
Princeton Plasma Physics Lab ... 681
Process & Cryogenic Services Inc. ... 680
Proto Manufacturing Ltd. ... 679
Raytheon Company, M&PT Division ... 678
Rehab R&D Center, VA Medical Center ... 677
RGB Spectrum ... 676
RG Hansen & Associates ... 675
Ribbon Technology Corp. ... 674
Rockwell International/Commercial GPS ... 673
Salco Circuits ... 672
Sandia National Laboratories ... 671
Seiko/Pacific Data Group ... 670
Silicon Graphics ... 669
Silma Inc. ... 668
Simmonds Precision Aircraft Systems ... 667
SMTEK ... 666
Sorbilite Inc. ... 665
Space News ... 664
Specialty Steel & Forge ... 663
SRI International ... 662
Stardent Computer Inc. ... 661
Statistical Sciences Inc. ... 660
Stennis Space Center ... 659
Stephens Analytical ... 658
Stereographics Corporation ... 657
Strategic Defense Initiative Organization ... 656
Sun Microsystems ... 655
Symbolics Inc. ... 654
Systems Control Technology Inc. ... 653
Technology Access Report ... 651
Technology Transfer Society ... 650
Technology 2002 ... 649
Tennessee Technology Foundation ... 648
Thin Film Technology Inc. ... 647
Tiodize Inc. ... 646
Triodyne/Department of Energy ... 645
Ultramet ... 644
United Magnet Technologies ... 643
Univ. of Dayton Research Institute ... 642
USAF Manufacturing Technology Directorate 641
US Army Electronics and Technology Devices Lab ... 638
US Army Laboratory Command ... 637
USBI Corporation ... 640
USDA, Agricultural Research Service ... 639
US Department of Energy ... 635
US Department of Energy Conservation and Renewable Energy ... 636
US Geological Survey ... 634
Vector Aeromotive Corporation ... 633
Viking Labs Metrum ... 632
Virginia Center for Innovative Technology ... 631
Wolfram Research ... 629

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comes the foregoing limitations.

In developing the new technique, the primary objective was to develop a method to distribute uniformly-thin powder-metal-alloy layers between alternate fiber layers prior to consolidation. In one demonstration, a blend of two fine (200-mesh) titanium aluminide (65Ti/24Al/11Nb and 51Ti/48Al/1V, where the numbers denote weight percentages) powders was used. A slurry was made by mixing small amounts of deionized water with the powder blend to obtain a mudlike slurry. The slurry was then transferred onto a stainless-steel sheet to which thin rails had been spotwelded (see Figure 1). The rails controlled the thickness of the powder as it was smoothed with a doctor blade. This operation was performed with the stainless-steel sheet resting on a sheet of glass. Next, the entire assembly consisting of the sheet of glass and the stainless-steel sheet covered with the slurry was placed in a freezer to freeze the water in the slurry.

When composite layup is required in production, assemblies like the one described above are to be removed from a freezer, and the stainless-steel sheets are to be flexed slightly to separate the frozen alloy-powder sheets from them. The frozen alloy-powder sheets can then be placed in an appropriate stack between reinforcing fibers. The stack is then to be vacuum-outgassed at a temperature of 400 to 500 °C to remove the water. Finally, the stack of alloy-powder and fiber layers is to be consolidated. In an alternative version of the process, one could embed a fiber mat inside the slurry prior to freezing to obtain sheets that could be consolidated directly into a composite.

In the demonstration, a composite of the blended titanium aluminide powders and silicon carbide fibers (see Figure 2) was prepared by the new technique and consolidated. Consolidation was performed in a constrained die in which some flow of the matrix was allowed only along

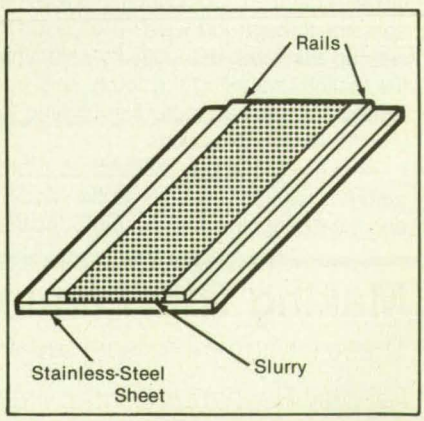


Figure 1. The **Slurry Was Spread Out** and leveled between the rails, then frozen. The sheet of frozen slurry was then removed from the stainless-steel sheet and used as one of the layers of a composite layup.

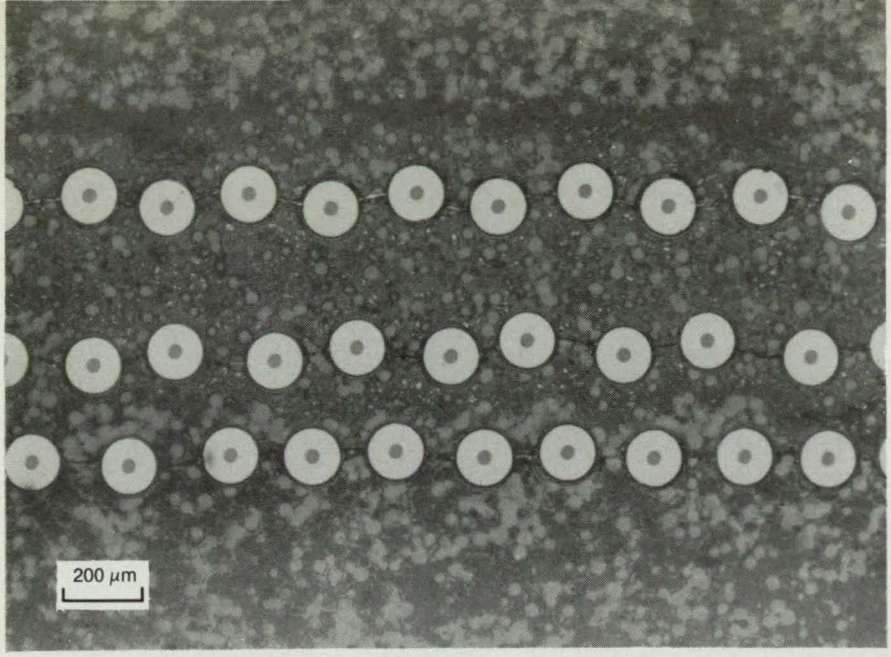


Figure 2. This is a **Magnified Cross Section** of the titanium-alloy/silicon carbide-fiber composite made by the technique described in the text.

(not across) the fibers. Such constrained deformation is believed to improve the quality of the alloy matrix by elimination of prior particle boundaries between the powder particles deformed in the process. In the microstructure of the resulting composite, the layers of alloy matrix between rows of fibers were found to be of uniform thickness and well bonded.

In addition to aerospace applications, this technique, appropriately modified, could have potential in the manufacture of future automobile engines or components that include molded ceramics.

This work was done by A. K. Ghosh, L. M. Holmes, R. B. Houston, and G. M. Ecer of Rockwell International Corp. for **Langley Research Center**. *No further documentation is available.*

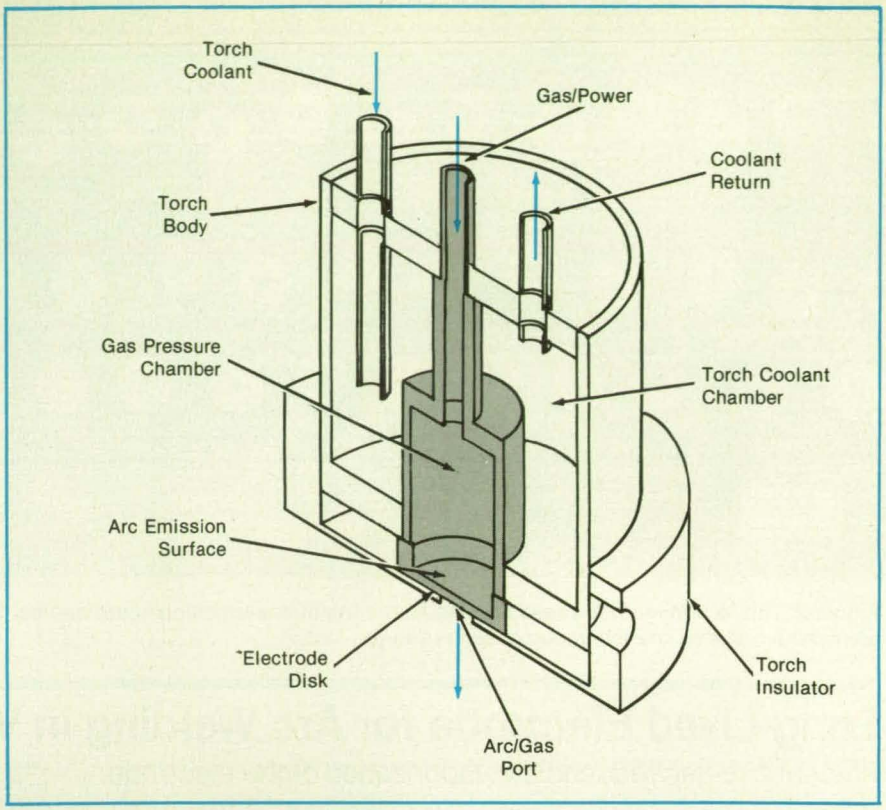
Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Langley Research Center [see page 16]. Refer to LAR-14111.

Long-Lived Electrode for Arc Welding in Vacuum

Pressurized gas reduces the vaporization of the electrode.

Marshall Space Flight Center, Alabama

An improved electrode for gas/tungsten arc welding in vacuum is essentially a hollow cylinder along which an inert gas flows. The interior of the cylinder provides a large surface area for the emission of electrons to form the welding arc. The flow of pressurized inert gas inhibits vaporization of the hot electrode material. Both features combine to reduce the erosion of the elec-



The **Electrode for Welding in a Vacuum** is a hollow tungsten cylinder. An insulator holds the electrode in the welding torch. Inert gas flows into the cylinder along the central tube at the top. The inert gas flows out through the orifice in the bottom end of the electrode.

trode. Consequently, the electrode lasts considerably longer in a vacuum than does a conventional electrode.

The outer end of the electrode has a small orifice to release the inert gas and the arc (see figure). The electrode is held in a nonconductive cup, which confines the origin of the arc to the orifice; this prevents extraneous corona discharge to other spots on the outside of the welding torch.

For welding in a vacuum chamber, the diameter of the orifice is 0.005 to 0.010 in. (0.13 to 0.25 mm), and the volume of the cylindrical cavity in the electrode is about 0.75 $in.^3$ (about 6.9 cm^3). These dimensions ensure the emission of an adequate number of electrons for the arc while limiting the flow of inert gas into the vacuum chamber so as not to exceed the capacity of the vacuum pump.

This work was done by Jack L. Weeks and Richard M. Poorman of Rockwell International Corp. for **Marshall Space Flight Center**. *For further information, Circle 3 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 16]. Refer to MFS-29766.

Mathematics and Information Sciences

Developing Software for a Flight-Control System

Integration of design activities reduces the incidence of errors.

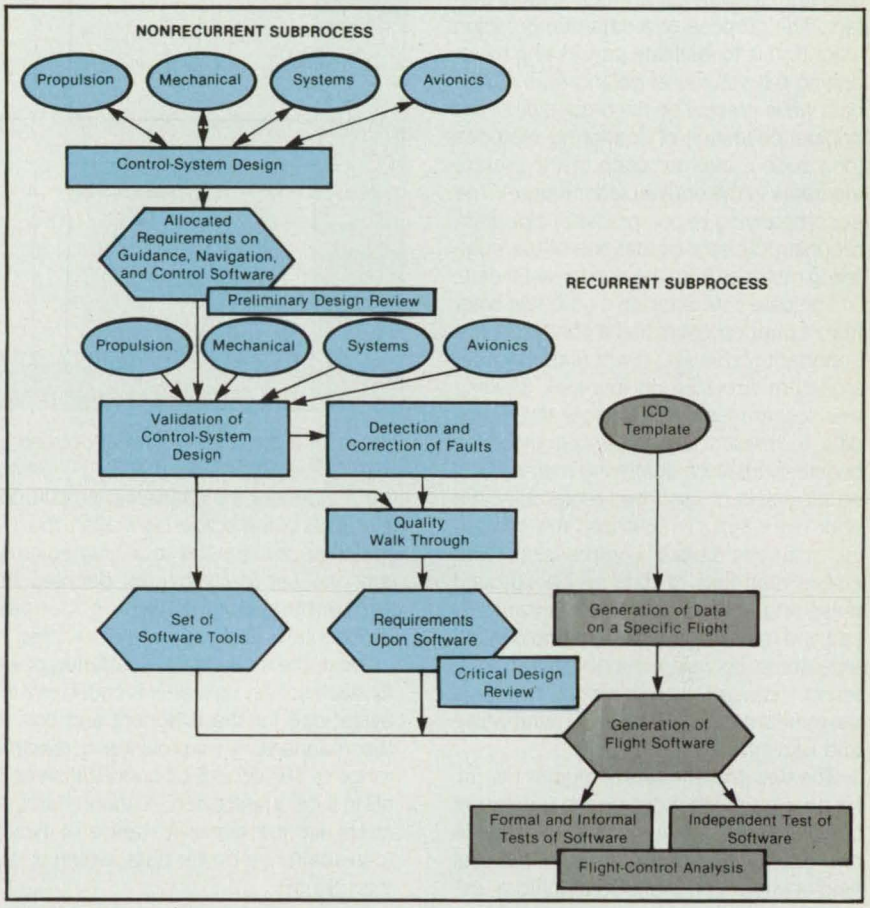
Marshall Space Flight Center, Alabama

An improved process for the development of flight-control software has been devised by integrating the conventional software-development process with the conventional control-system-analysis process. Historically, these latter two processes have been regarded as independent of each other. The integration of them reduces the costs of development dramatically, eliminates the need for reengineering, and almost eliminates production errors. The concept of the integrated design process may be applicable to the design of other control systems and of complicated hardware-and-software systems in general.

In the integrated design process, a control system is designed in three phases. The control concept is designed in the first phase, in which the control engineer sets requirements that have to be satisfied by recourse to noncontrol engineering disciplines. These include such requirements as stiffnesses of structures. The second phase involves the design and validation of the control system. This phase includes the testing of the source version of the control software by a process of computer modeling of the behavior of the entire system of control software, controlling hardware, and controlled hardware. In the third phase, the object code that is to be used in the computer or computers of the control system is generated and validated.

The approach taken in the integrated design process ensures that requirements at each stage are understood fully before engineering proceeds. The control engineer does not have to make ad-hoc modifications to an otherwise final design, and the software engineer has only to integrate the design into the computer or computers in the control system. Design errors and redesign activity are almost eradicated, and large increases in productivity are effected.

The figure illustrates the development of flight-control software by an integrated design process. To meet those engineering requirements that are oriented toward life cycles, software that effects guidance, navigation, and control functions is integrated into the flight software from the beginning. The effect is to eliminate the reengineering of software and provide a clear method of ensuring quality. Also, emphasis is placed upon the integration of subsystems in the design of the control system.



The **Process of Development of Flight Software** includes recurrent and nonrecurrent subprocesses.

The design process starts with a broad conceptual design of the control system (including provisions for guidance and navigation functions). The acceptable design of each subsystem is predicated upon the ease with which the control system can function. For example, a suitably rigid structure facilitates the development of a simple set of control algorithms; this, in turn, facilitates the required automation of the generation of the object code to be used in the computer or computers of the control system. Similarly, in the case of a spacecraft, the layout of the reaction-control subsystem can be instrumental in the design of thrustor-switching logic that provides redundancy of functions; this, in turn, obviates expensive built-in testing for the management of redundancy.

Once the design process reaches preliminary design review, the boundary conditions for a robust guidance, navigation, and control system have been set. The next step is the validation of the design, after which the initial flight source code will have been completed by the control engineer and will be ready for critical design review. At this stage, the software engineer completes the definition of requirements upon software ready for coding.

The nonrecurring component of the design process is completed with the establishment of the common set of software tools. The recurring component of the design process is simply one of generation of macro descriptive language and integration into the flight code to generate the object-code version of the flight software. The common set of software tools is then used to validate performance and post-flight analysis.

This work was done by Jonathan Murray of Martin Marietta Corp. for **Marshall Space Flight Center**. *No further documentation is available. MFS-28461*

Algorithms for Compression of Polarimetric-Radar Image Data

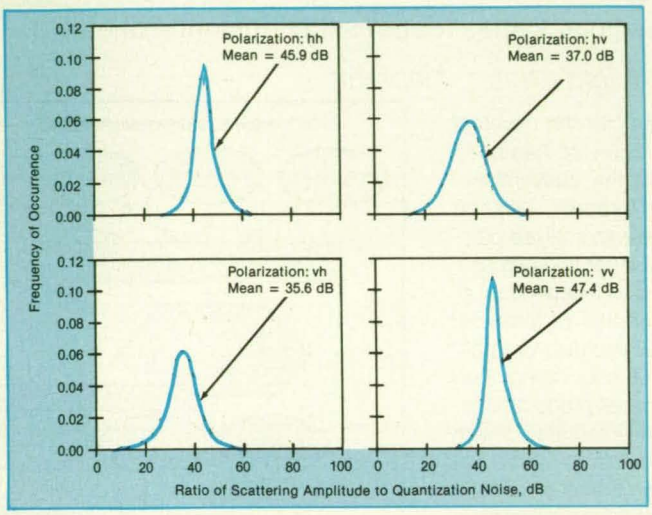
Data on background noise and effects of equipment are retained.

NASA's Jet Propulsion Laboratory, Pasadena, California

Two sets of algorithms provide moderate improvements in the compression and decompression of scattering-matrix data from a polarimetric imaging radar system. The purpose of a data-compression algorithm is to facilitate processing by reducing the volume of polarimetric image data while preserving the properties of the original collection of scattering matrices (one such matrix for each of the picture elements in the original radar image). The accompanying decompression algorithm reconstructs approximations of the scattering matrices from the compressed data.

The data-compression algorithms differ from a prior-compression algorithm in two important respects: (1) whereas the prior algorithm operated on four-look Stokes-matrix averages of the original single-look data, the present algorithms operate on the original single-look scattering matrices; (2) on the basis of assumed reciprocity, the prior algorithm symmetrized the scattering matrices before compression, with consequent loss of data on background noise and nonreciprocity in the transmitting and receiving equipment. The present algorithms do not symmetrize the scattering matrices and, therefore, preserve asymmetrical data on background-noise and equipment effects.

The two present sets of algorithms differ from each other only in the number of bits used to quantize the data — 8 bits in one case, 4 bits in the other. In the first step of either compression algorithm, the complete set of scattering-matrix data for all picture elements is scaled by a single factor, called the "general scale factor." This factor is chosen so that the average, over all picture elements, of the total scattering power of each picture element is unity. As used here, the total scattering power of a picture element is defined as $\frac{1}{4}(|S_{hh}|^2+|S_{hv}|^2+|S_{vh}|^2+|S_{vv}|^2)$, where the S's denote the scattering amplitudes (elements of the scattering matrix), the first subscript denotes the receiving polarization, the second subscript denotes the transmitting polarization, h denotes "horizontal," and v denotes "vertical."



The **Signal-to-Noise Ratios** of compressed data in these histograms are computed from 8-bit-quantized scattering amplitudes and quantization noise from a 768,000-pixel polarimetric radar image of Goldstone Dry Lake in California. The average signal-to-noise ratio is greater than that of a data-compression scheme based on the Stokes-matrix formulation.

Next, the scaled total scattering power for each scattering matrix is coded into two bytes: one for the exponent and one for the mantissa. This provides a dynamic range of 765 dB in 8-bit quantization or 63 dB in 4-bit quantization — more than adequate for the dynamic range of typical total-scattering-power data, which is less than 30 dB.

Continuing the process of quantization within each scattering matrix, each scattering amplitude is divided by the quantized value of $(|S_{hh}|^2+|S_{hv}|^2+|S_{vh}|^2+|S_{vv}|^2)^{1/2}$, so that the real and imaginary parts of the matrix elements thus normalized lie in the range from −1 to +1. During the 8-bit compression, each real and imaginary normalized value is multiplied by 127 and coded as one byte. During the 4-bit compression each real and imaginary normalized value is multiplied by 7, and each pair of real and imaginary numbers is coded as one byte. The dynamic range of this quantization is 48 dB in the 8-bit case or 24 dB in the 4-bit case, and is in addition to the 765-dB (8-bit) or 63-dB (4-bit) range of the general-scale-factor quantization.

The 8-bit version divides the volume of data by a factor of 3.2, while the 4-bit version divides the volume by a factor of 6.4. The major disadvantage of these compression algorithms is that they introduce a small amount of quantization noise (see figure for the 8-bit results).

This work was done by Jakob J. Van Zyl and Charles F. Burnette of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 72 on the TSP Request Card. NPO-18240*

Object-Oriented Algorithm for Evaluation of Fault Trees

An algorithm reduces the number of calls needed to solve trees with repeated events.

Ames Research Center, Moffett Field, California

An algorithm for the direct evaluation of fault trees incorporates techniques of object-oriented programming. Fault trees represent interactions among the parts of complicated systems, and software techniques used to represent them must be capable of capturing complete information about the systems. The algorithm provides a significantly improved software environment for such computations as quantitative analyses of the safety and reliability of complicated systems of equipment (e.g., spacecraft or factories).

Object-oriented programming techniques are widely used in writing software for expert systems (artificial intelligence), graphics, system programming, the management of data, and other demanding applications. Object-oriented programming includes powerful features that enable the encapsulation of modules of code and pro-

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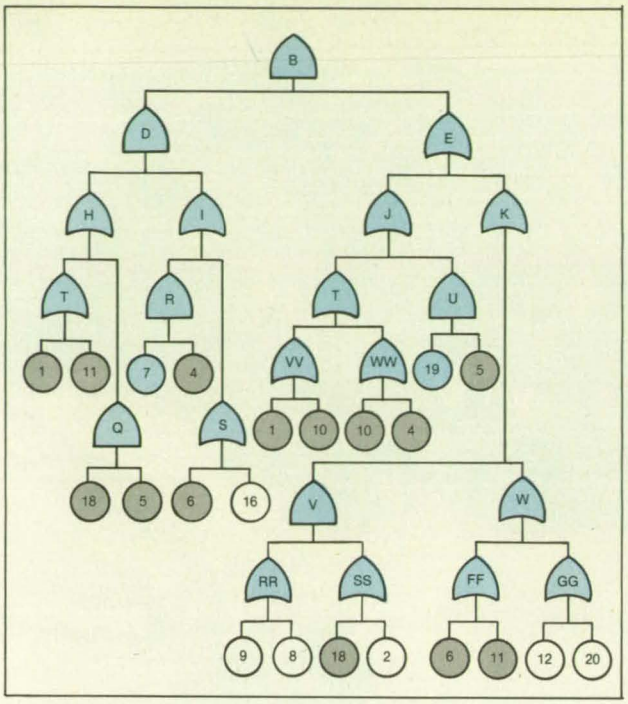
vide a unique software feature called "inheritance." These features are particularly useful in the development of software for the evaluation of fault trees.

The object-oriented algorithm for the evaluation of fault trees and the associated computer program were developed on a Texas Instruments Explorer LISP workstation. The program, which directly evaluates system fault trees, utilizes the object-oriented extension to LISP called Flavors that is available on the Explorer. The object representation of a fault tree facilitates the storage and retrieval of information associated with each event in the tree, including information on the structure of the tree and intermediate results obtained during the tree-reduction process. Reliability data associated with each basic event are stored in the fault-tree objects. The object-oriented environment on the Explorer also includes a graphical tree editor that was modified to display and edit the fault trees.

The evaluation of the fault tree is performed by use of a combination of standard fault-tree-reduction procedures. A bottom-up procedure is used for subtrees that do not contain repeated events, and a top-down, recursive procedure is used to evaluate subtrees that do contain repeated events (see figure). The tree is dynamically modularized according to the event being evaluated at the time. The locations of repeated events are propagated up the tree and stored in each event object. This information is used to determine which evaluation procedure is required for each event, and intermediate results are stored as they are calculated. Unlike most conventional fault-tree-evaluation codes, which calculate the probability of occurrence of the top event only, this program produces results for every event in the fault tree. The object-oriented approach to fault-tree reduction greatly increases the efficiency of the evaluation algorithms.



This **Fault Tree**, represented by AND and OR gates, contains 15 basic events, each of 7 of which is repeated at one other location.

This work was done by F. A. Patterson-Hine of **Ames Research Center** *and B. V. Koen of the University of Texas at Austin. For further information, Circle 32 on the TSP Request Card.*
ARC-12731

Thrust-Vector-Control System

Control gains are computed via a matrix Riccati equation.

Marshall Space Flight Center, Alabama

A software-based system that controls the aim of a gimbaled rocket motor on a spacecraft is adaptive and optimal in the sense that it adjusts its control gains in response to feedback, according to an optimizing algorithm based on a cost function. The underlying control concept may also be applicable, with modifications, to thrust-vector control on vertical-takeoff-and-landing airplanes, control of the orientations of scientific instruments, and robotic control systems.

The system generates a gimbal-deflection command to rotate the gimbal and thereby deflect the thrust vector. The control algorithm, which is of the proportional/integral/derivative type, computes the gimbal-angle command from the error in the attitude and the rates of rotation of the main spacecraft body (see figure).

The optimizing algorithm computes the feedback gains for the control algorithm by use of the discrete form of the matrix Riccati equation. This equation is derived, in turn, by use of a Lyapunov function in discrete space. The matrix Riccati equation is solved by backward integration. The solution must be reformulated by use of a nominal starting condition to prevent numerical instabilities.

The optimizing algorithm can be summarized as follows:

1. Initialize the Lyapunov function by use of the Lyapunov Q cost index.
2. Calculate the discrete **A** and **B** matrices of a system from the continuous, time-varying **A** and **B** matrices, where **A** and **B** are the matrices in the following equation for the system, which is considered to be piecewise continuous:

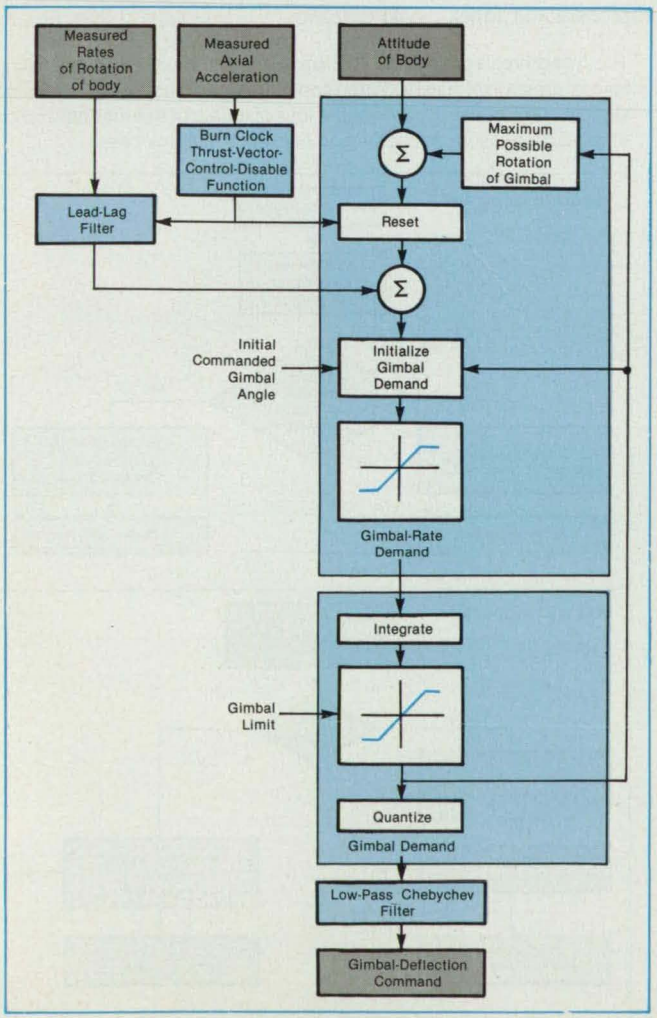
$$\frac{d}{dt}\left[X\exp^{-A\Delta t}\right] = \exp^{-A\Delta t}Bu$$

3. Calculate the optimal state-feedback gains.
4. Calculate the closed-loop **A** matrix.
5. Integrate the Lyapunov function backwards.
6. Transform the state-feedback gains into reset and phase-advance form.
7. Repeat steps 2 through 6 until the initial time has been reached.
8. The reset and phase-advance gains can then be curve-fit for implementation in the control system.

The cost indexes are determined heuristically such that the closed-loop pole positions provide suitable rigid-body response. Once set, the cost indexes do not have to be changed. It can be shown that this optimal control provides a minimum phase margin of 60°. Given adequate separation of the rigid-body modes from the gimbal, this margin is maintained until the end of flight, when inaccuracies in the curve fit reduce the margin to 30°. This is more than adequate to meet the end-of-flight stability requirement.

This work was done by Jonathan Murray of Martin Marietta Corp. for **Marshall Space Flight Center**. *For further information, Circle 34 on the TSP Request Card.*
MFS-28462

The **Control Algorithm** operates in conjunction with an optimizing algorithm (not shown), which computes its feedback gains.



Adaptive Vector-Quantization Scheme

Audio, video, or other signals are compressed efficiently.

NASA's Jet Propulsion Laboratory, Pasadena, California

An adaptive vector-quantization scheme provides for the rapid encoding of signals for transmission in compressed form and for rapid decoding at the receiver. The scheme is versatile enough to be useful with a variety of signals; e.g., audio, video, and text.

Unlike some prior data-compression schemes, this one does not require advance knowledge of the statistics of the source signal and does not require the advance computation of a codebook. In this scheme, the codebook is generated "on the fly" and repeatedly adapted to capture the recent features of the source signal by use of a simple heuristic algorithm. The only arithmetic operations needed in this scheme are addition and subtraction, and the simplicity of the scheme lends itself to rapid implementation in both software and hardware. For these advantages, one pays a modest price in the form of a partial loss of data (distortion) during the encoding process.

The adaptive vector-quantization scheme (see figure) is based on a simple heuristic "move-to-front" protocol that effects lossless compression of high-rate textual data. For the purpose of this scheme, the protocol is modified to effect lossy compression of low-rate speech, image, or other analog data. The source data are grouped in chronological sequence into vectors. The encoder constructs a codebook in the form of an indexed list of data vectors (the code words) in order of decreasing statistical frequency. Both the encoder and the decoder maintain the same list, which is repeatedly updated with new source data in such a way that the more-recently-used code words are closer to the top of the list. Code words that have not been used for a long time are pushed toward the bottom of the list and eventually discarded.

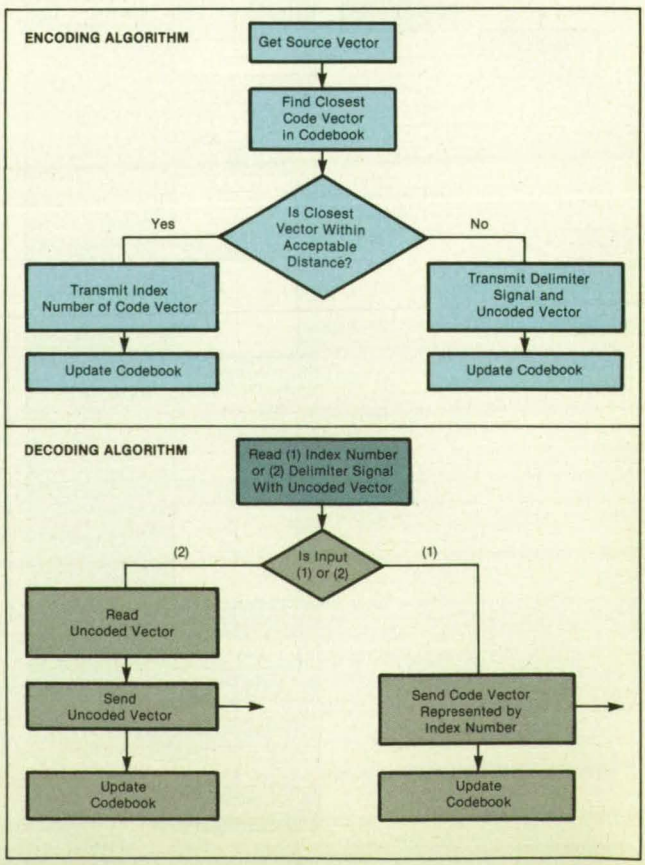
A source vector is encoded by representing it with the index number of the code vector that approximates it most closely. The index numbers tend to be small rather than large. These index numbers can be further compressed using an entropy coder like a Huffman code, an arithmetic code, or an Elias code. Compression is thus achieved because fewer bits are needed to represent the index number than to transmit the quantized, source-vector data. The particular code vector, being the one most recently used, is moved to the top of the code list.

Occasionally, the distance between the source vector and any code word on the list exceeds a specified level that represents the maximum acceptable encoding distortion. In that case, the quantized source vector is transmitted uncoded, in its entirety, along with a "delimiter" signal that indicates that this is being done. This vector is then placed at the top of the code list, the other entries are moved down the list one slot, and the bottom entry on the list is discarded.

Because the same codebook is maintained in both the decoder and the encoder, decoding is straightforward. The decoder generates the decoded vectors from the received signal by using the received index numbers to refer to code vectors on the list, or by passing on the uncoded vector when it receives such a vector with its delimiter signal.

This work was done by Kar-Ming Cheung of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 45 on the TSP Request Card.*
NPO-18186

The **Adaptive Vector-Quantization Scheme** provides efficient coding for compression of signals. When applied to video, audio, or other analog signals, the sheme results in some loss of data, but this loss may be an acceptable price for economy and efficiency in many cases.



Life Sciences

Tubular Membrane Plant-Growth Unit

A hydroponic system controls nutrient solution for growing crops in space.

John F. Kennedy Space Center, Florida

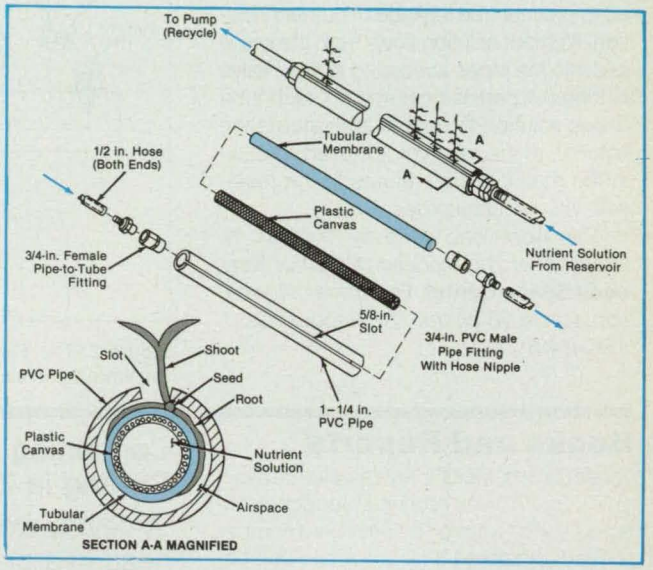
This system controls plant-nutrient-solution delivery to the roots of plants for the purpose of supporting plant growth in the microgravity of space. Initial tests have shown that a number of crop plants such as wheat, rice, lettuce, tomatoes, soybeans, and beans can be grown successfully with this system.

The initial design of the system includes a porous tube of plastic canvas surrounded by a hydrophilic porous membrane and an outer shell of polyvinyl chloride (PVC) pipe. In later designs, the porous membrane and plastic canvas tube are replaced with a rigid hydrophilic, porous polyethylene or ceramic tube. Nutrient solution flows through the porous tube under a slight negative gauge pressure (suction). The surface tension of the solution prevents it from flowing freely out of the membrane and prevents air from entering.

The plants grow in an axial slot in the PVC pipe, drawing solution from the tube by capillary attraction to the roots in contact with the porous membrane (see figure). The PVC pipe shades and protects the roots. Standard PVC plumbing fittings join the inner porous tube to a supply tank and pump.

The membrane is made of a hydrophilic acrylic copolymer cast over a nylon substrate, which gives it strength. It contains pores 0.2 to 0.45 μm wide. The sheet of membrane is folded and stitched into a tube slightly narrower than the PVC pipe (which is 1 ¼ in. (3.2 cm) in diameter). The seam is sealed with a hot-melt adhesive. To make the tube of plastic canvas that supports the membrane, a 3-in.- (7.6-cm)-wide strip of the canvas is rolled around its long axis and inserted in the membrane tube. This assembly is inserted into the PVC pipe, in which a slot, 5/16 in. (0.8 cm) wide, has been cut.

Seeds are placed in the slot to germinate normally. Their roots grow along and around the membrane tube.



A Pump Draws Nutrient Solution along the inside of the tubular membrane in the pipe from a reservoir, maintaining a negative pressure in the pipe. Roots of plants in the slot extract nutrient through the membrane within the pipe.

This work was done by Thomas W. Dreschel of The Bionetics Corp. for **Kennedy Space Center**. *For further information, Circle 79 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Kennedy Space Center *[see page 16].* *Refer to KSC-11375.*

Monitoring and Controlling Hydroponic Flow

A simple apparatus maintains the required slight suction while overcoming gravity effects.

John F. Kennedy Space Center, Florida

A pressure-monitoring and -controlling apparatus maintains the slight suction required on the nutrient solution in the apparatus described in the preceding article "Tubular Membrane Plant-Growth Unit" (KSC-11375), while overcoming gravity effects on the operation of the system on Earth. The suction helps to hold the solution in the tubular

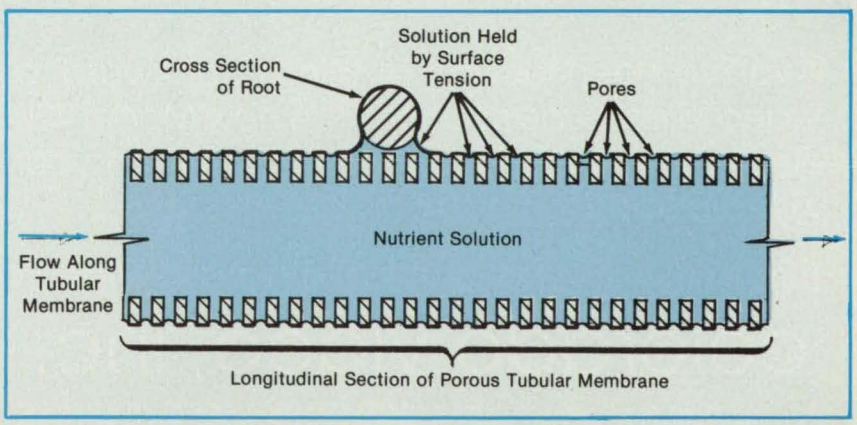


Figure 1. The **Surface Tension** of the solution seals the pores, and a slight negative gauge pressure in the solution holds the solution inside until contact with the root draws the solution out by capillary action. The negative pressure partly counteracts the capillary action, limiting the degree to which the solution flows out before surface tension takes over.

membrane (see Figure 1).

A submersible pump circulates nutrient solution from a reservoir to an inlet manifold for the growth tubes. A pair of standpipes help maintain a steady pressure in the manifold. A gauge provides a continuous indication of the pressure at the inlet of each growth tube in an array of such tubes (see Figure 2). An operator can adjust the pressure in each tube individually, by means of a needle valve, to obtain the slight negative pressure that is needed to prevent free leakage of nutrient solution. Nutrient solution flows from the manifold into the pipes according to their valve settings. A peristaltic pump on each tube draws solution through it and returns the solution to the reservoir. Unused solution in the manifold also returns to the reservoir via the standpipes.

This work was done by Thomas W. Dreschel of The Bionetics Corp. for **Kennedy Space Center**. *For further information, Circle 78 on the TSP Request Card.*
KSC-11416

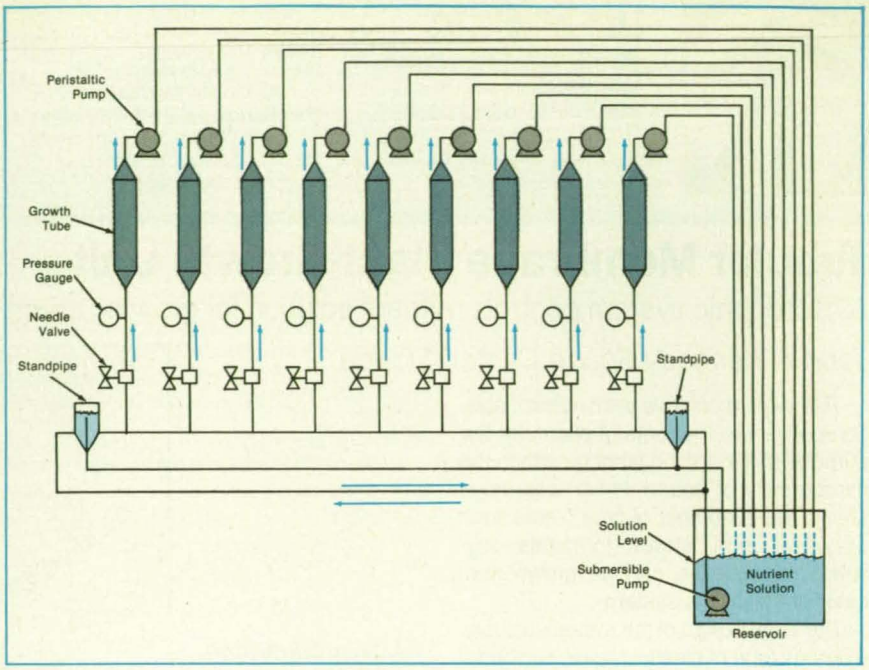


Figure 2. The **Flows of Nutrient Solution in and From Growth Tubes** are individually monitored and controlled with pressure gauges and needle valves.

Books and Reports

These reports, studies, handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Containing Hair During Cutting in Zero Gravity

A device would enclose the head in a plastic bubble while a barber works.

A proposed device described in a brief report would collect loose hair during barbering and shaving in zero gravity to prevent hair clippings from contaminating the cabin of a spacecraft. The device, which would be folded for storage, would open into a clear, bubblelike plastic dome that surrounds the user's head, a tray that fits around the user's throat, and a fanlike ring that surrounds the back of the neck. The device would fit snugly but comfortably around the neck, preventing hair from escaping to the outside. The flow of air into a hose connected to a suction pump would remove hair from the bubble as it is cut. A filter at the end of the hose would collect the hair.

In space, where microgravity would allow haircuttings to float freely within the bubble until sucked out by the pump, the user would breathe through a mouthpiece and air tube connecting to the outside so as not to inhale cuttings. The user would keep eyes closed or wear small goggles during cutting.

The barber would insert hands into the bubble through snugly fitting holes. The barber could introduce the haircutting tools through the holes. Alternatively, the implements would be mounted on the tray, inside the bubble, in fixtures that hold them securely but allow quick and easy removal. In space, of course, both the device user and the barber would need foot and body restraints to hold themselves in position.

This work was done by Richard F. Haines of **Ames Research Center**. *To obtain a copy of the report, "Microgravity Barbering/Shaving Facility," Circle 69 on the TSP Request Card.*
ARC-11668

Human Adaptation to Isolated and Confined Environments

Physiological and psychological data from an Antarctic research station are analyzed.

A report describes a study of the physiology and psychology of humans in an isolated and confined environment. It suggests ways in which such environments can be made more acceptable to human inhabitants.

The study was conducted during the 7 months of an Antarctic winter tour of duty at Palmer Station in the mid 1980's. The results are important to the design of facilities for those who must work in other hostile and potentially lethal environments. In addition, the study provides information about the physiological and psychological stress that may be experienced in an isolated and confined environment. For example, the Space Station will confine and isolate its inhabitants for long periods. Navy submarines routinely go on 60-day patrols in which outside communication is extremely limited. Oil companies employ professional divers who must remain in hyperbaric chambers for a month at a time.

In the study, blood pressure was measured twice per week, and concentrations of the hormones epinephrine (adrenalin) and norepinephrine in the urine were measured once per week. Data from subjects' reports on their own moods (anxious vs. composed, hostile vs. agreeable, depressed vs. elated) were collected three times per week. Records of weather, journal entries made by the investigator, and information on the use of station facilities were also collected.

Concentrations of epinephrine and norepinephrine dipped significantly around the middle of the winter. On the other hand, the effects of the length of stay did not appear to have any significant effect on blood pressure. There was a linear increase in reports of feelings of hostility and anxiety during the winter, but there was no significant increase in depression. The physiological and psychological data did not change in a synchronous fashion.

Anxiety increased in proportion to the number of hours spent on work. The people who reported the greatest variety of personal activities were the least depressed, hostile, and anxious of the crew.

The results offer guidelines for the design of isolated and confined facilities.

- People brought similar items to make themselves feel at home — music, clothing, food, photography equipment, photographs of loved ones, and books. Such items should be included in the standard equipment, and space should be provided in private areas for displaying photographs.
- All attempted to personalize public and private areas. Again, materials should be provided so that people can change their environment to make it theirs.
- Flexible environments helped to create novelty and new stimuli in a low-stimulus environment. Furniture and wall hangings, for example, should be easy to rearrange.
- Sixty percent of waking hours were spent alone. Bedrooms were used extensively as places to obtain privacy. Thus, areas that give visual and auditory privacy are necessary.
- People nevertheless also felt the need to socialize, underscoring the importance of placing public rooms near high-traffic areas, well-removed from private quarters, and equipping them with music, food, game tables, videos, and comfortable, movable furniture. Social areas that might have conflicting uses should be separate.
- The gym was in use from morning until evening. Most hobbies involved physical or manual activity. Thus, recreational areas are crucially important.

This work was done by Gary W. Evans, Daniel Stokols, and Sna Sybil Carrere of the University of California at Irvine for **Ames Research Center**. *Further information may be found in NASA CR-177499 [N89-15531], "Human Adaptation to Isolated and Confined Environments: Preliminary Findings of a Seven-Month Antarctic Winter-over Human Factors Study."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
ARC-12582

Cardiovascular Effects of Weightlessness

Responses of humans and animals to real and simulated weightlessness are reviewed.

A NASA technical memorandum presents a study of the effects of weightlessness and simulations thereof upon the cardiovascular systems of humans and animals. It reviews research up to the year 1987 in the United States and Soviet space programs on such topics as the physiological changes induced by weightlessness in outer space and by the subsequent return to Earth gravity and also reviews the deconditioning effects of prolonged bed rest on the ground (as an approximation to the deconditioning effects of weightlessness).

After a brief introduction that describes the general deconditioning effect of weightlessness, the report discusses the role of gravity in the functions of the cardiovascular system. The next chapter describes experiences in United States and Soviet space flights that carried humans and animals, which were instrumented and/or housed for observation in various ways. The following chapter describes a variety of ground-based experiments, including immersion in water, bed rest, chair rest, confinement, and the use of partial-body-supporting systems to simulate weightlessness; observations of responses to orthostatic stress (the stress of standing up) after bed rest; the use of centrifuges and gravity suits to study the effects of, and countermeasures to, acceleration; studies of the effects of exercise on athletes and nonathletes; studies of the effects of differences in age and sex; and laboratory experiments on animals.

The next chapter discusses the roles of various physiological mechanisms. Topics include changes in the volumes of bodily fluids, alterations in cardiac function, changes in the capacities and compliances of blood vessels, and impairment of cardiovascular reflex control. The following chapter discusses measures to offset the effects of weightlessness; these include exercises, pressure suits, centrifugation, and drugs. The last chapter summarizes the findings reported in the previous chapters.

The report states a number of conclusions, including notably the following:

- Cardiovascular deconditioning occurs during both space flight and simulation, and the effects are most pronounced when the body is erect.
- The hemodynamic parameters of the deconditioned state (as compared with those of the preconditioned state) indicate that deconditioning is characterized by excessive tachycardia, hypotension, decreased heart volume, decreased volumes of plasma and circulating blood, and loss of skeletal-muscle mass, particularly in the lower limbs.
- Available data indicate that the mechanisms involved with the regulation of the volumes of bodily fluids, the altered cardiac function, and the neurohumoral control of the peripheral circulation play significant roles causing the observed changes.
- Satisfactory countermeasures have not yet been found.
- Hemodynamic changes immediately after a flight are best handled by lower-body counterpressure ("antigravity") suits.
- The return to the preflight state can take weeks or months and is only slightly dependent on the duration of the flight.

This work was done by Harold Sandler of **Ames Research Center**. *Further information may be found in NASA TM-88314 [N88-25140], "Cardiovascular Effects of Weightlessness and Ground-Based Simulation."*

Copies may be purchased [prepayment

3M Reduces Solvents Used In Electrical Tape Manufacturing

Reduction of solvent usage assures users of future tape availability as worldwide environmental concerns heighten

AUSTIN, Tex. — The 3M Electrical Specialties Division is implementing solvent reduction processes in the manufacture of OEM insulating electrical tapes. The established goal is to reduce solvent purchases and usage by 80 percent.

Customers incorporating these insulating tapes in present products, re-designs and new products will be assured of a reliable source well into the 21st Century.

New sixteen page brochure describes over 50 Scotch electrical tapes for OEM applications, and other electrical insulation products.

3M is also taking a holistic view of its efforts to achieve a cleaner environment, believing that it is important to examine the full scope of a product's impact on the environment – beginning with product design and the manufacturing process, and extending to product usage, packaging and disposal.

The tapes are designed for use in OEM electrical applications to insulate, hold, protect and identify electrical conductors, components and circuits. Solvent reduction processes will be extended to as many OEM electrical tapes as possible. The following tapes with a thermosetting rubber-resin adhesive have already been released:

No. 2 and 38 Crepe Paper
No. 27 Glass Cloth
No. 46, MR 98 Polyester Film/ Glass Filament
No. 44, 55, 1174, MR 93, MR 93B, MR 94, MR 94B Polyester Film/MAT
MR 96 Polyester Film

For more information, contact a 3M Electrical Specialties Division representative or authorized distributor, or call 1-800-233-3636.

3M Electrical Specialties Division
6801 River Place Boulevard
Austin, Texas 78726-9000

3M

required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703)487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
ARC-12527

Deconditioning Under Prolonged, Repeated Bed Rest

Recovery takes longer than previously thought, and effects seem to be cumulative.

Cardiovascular deconditioning from prolonged bed rest is not counteracted by mild exercise and requires at least 3 weeks for recovery, a report contends. Deconditioning involves more than a simple decrease in the volume of plasma; neurohumoral mechanisms, loss of mass of skeletal muscles, and a general decrease of the body's metabolic needs seem to be major contributors.

The conclusions are based on a study of seven subjects who rested in bed for three 2-week periods and spent 3 weeks in ambulatory recovery between rest periods. The subjects were males, aged 19 to 21, who were participants in a college physical-education program. The study was intended to examine the recovery process and its applicability to future Space Shuttle crewmembers, who may be asked to fly another mission after an interval of only 2 or 3 weeks.

The subjects exercised isometrically and aerobically every day during bed rest and recovery. Each man operated an ergometer at 68 percent of his maximum oxygen intake for 30 minutes, morning and afternoon, and did isometric leg exercises for another 30 minutes twice a day.

Subjects were exposed to suction on the lower parts of their bodies several times during the study while their heart rates and arterial blood pressures were measured. The data suggest that deconditioning effects may be cumulative. For example, the heart rate increased an average of 13.3, 35.1, and 51 percent for each of the three pre-bed-rest measurements under a suction of 40 mm of mercury (5.3 kPa).

The heart rate and the left ventricular end-diastolic volume index, both measured under suction, proved to be the parameters that exhibited the greatest changes. While the volumes of bodily fluids returned to their normal levels within 2 days after bed rest ended, both the heart rate and the left ventricular end-diastolic volume index had not returned to normal after 3 weeks. Apparently, the exercises performed by the subjects did little or nothing to prevent deconditioning.

This work was done by Harold Sandler, Richard L. Popp, and Donald C. Harrison of the Stanford University School of Medicine for **Ames Research Center**. *To obtain a copy of the report, "The Hemodynamic Effects of Repeated Bed Rest Exposure," Circle 90 on the TSP Request Card.*
ARC-12172

An ATPase From *Halobacterium Saccharovorum*

The purification and subunit structure of a halobacterial enzyme are described.

A report describes the purification and the determination of the subunit structure of a membrane-bound adenosinetriphosphatase (ATPase) from the archaebacterium *Halobacterium saccharovorum*. In analyzing the molecular structure, the authors took advantage of the observation that cold inactivates the enzyme and causes it to dissociate into subunits. The dissociation, which is irreversible, was shown to be the cause of the inactivation.

Membranes were prepared from *H. saccharovorum*. The enzyme was extracted from the membrane by use of detergent in two steps. The first step resulted in the extraction of about 54 percent of the membrane protein and left about 75 percent of the ATPase activity still associated with the membranes. In the second step, 7 percent of the remaining protein and essentially all of the remaining ATPase activity were extracted, although only 60 percent of that activity was recovered after gel filtration.

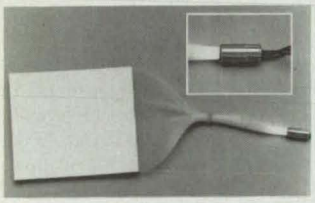
The enzyme was then solubilized by use of sodium deoxycholate and Zwittergent 3-10 and separated into fractions by hydrophobic and ammonium sulfate-mediated chromatography. After ammonium sulfate-mediated chromatography, a seventy-fold purification had been achieved, with retention of 13 percent of the initial ATPase activity. Gel-permeation chromatography and polyacrylamid-gel electrophoresis indicate that the native enzyme has a molecular mass of 350 kDa and includes two major (87 and 60 kDa) and two minor (29 and 20 kDa) subunits. It appears to be the unlike any ATPase described previously.

This work was done by L. I. Hochstein of **Ames Research Center** *and H. Kristjansson and W. Altekar of the National Research Council. To obtain a copy of the report, "The Purification and Subunit Structure of a Membrane-Bound ATPase from the Archaebacterium* Halobacterium Saccharovorum," *Circle 76 on the TSP Request Card.*
ARC-11855

New on the Market

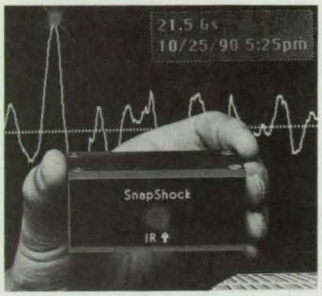
Fluid Dynamics International, Evanston, IL, has released FIDAP/PC 6.0, a DOS-based version of its **computational fluid dynamics software** for simulating a wide range of fluid flows using the finite element method. Version 6.0 includes a segregated iterative solver that dramatically reduces run times and disk storage requirements. Other new features include residence time calculations and particle tracking for a dispersed second phase in solution.
Circle Reader Action Number 628.

Lumitex Inc., Cleveland, OH, has introduced a white, **incandescent light source** to its line of woven, fiber optic backlighting products. Featuring a 5 volt, 20 mA lamp mounted in a .7" x .31" reflector, it provides dimmable backlighting for membrane switches and LCDs, without the electrical noise and environmental instability of electroluminescent backlighting. Its low power, low current requirements and small size make it suitable for portable or handheld devices.
Circle Reader Action Number 626.



The industry's highest-capacity single-board **frame buffer** for digital imagery is available from Viewgraphics Inc., Mountain View, CA. Called the Viewstore, it holds up to 384 MB of 24-bit true color image data on a single 9U x 400 nm VME board, providing on-board storage for one 10,000 x 10,000 pixel true color RGB image, 72 HDTV images, or 372 standard TV images. It allows fully-interactive user interfaces to be applied in multimedia and virtual reality research, satellite image analysis, geophysical mapping, and medical imaging.
Circle Reader Action Number 623.

The VME300-E **single-board computer** from Aeon Systems Inc., Albuquerque, NM, merges the power of the VAX architecture and the speed, accessibility, and economy of the VMEbus as a front-end. A fully-distributed, real-time process control system, the VME300-E can run complex process control programs requiring up to 16 MB of local memory. A built-in SCSI port allows the user to build independent, stand-alone machines without an external interface.
Circle Reader Action Number 624.

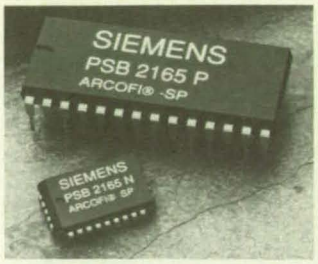


SnapShock®, a miniature, single-axis **peak-acceleration sensor/recorder** from Instrument Sensor Technology, Lansing, MI, accurately records peak-g levels, time, and date, with storage for 248 levels and independent operation for up to 70 days. Features include a built-in accelerometer sensor, DC to 320 Hz frequency response, infrared link for configuration and data recovery, data upload to an MS-DOS-compatible computer, and a rugged, waterproof housing.
Circle Reader Action Number 627.

A patented **energy storage** device from Quadri Electronics Corp., Chandler, AZ, provides nearly 100 times the storage density of wet slug tantalum capacitors and, when used with CMOS RAM to provide nonvolatile memory, overcomes many problems inherent in lithium and nickel cadmium batteries. A solid-electrolyte, radiation-hard device, HYPERCAP™ can be deep-discharged and recharged tens of thousands of times. It contains no lithium or toxic chemicals, will not outgas, explode, or ignite, and operates over a range of -55°C to 125°C.
Circle Reader Action Number 622.

The V-scope, a new system for **non-contact measurement** of an object's position and motion has been developed by Celesco Transducer Products Inc., Canoga Park, CA. Employing a combination of infrared, ultrasonic, and microprocessor technologies, the V-scope can simultaneously measure the position of up to eight independent bodies in 3D, and can determine velocity and acceleration. It measures distances to 200" with resolution better than .004" and a maximum sampling rate of 200 Hz.
Circle Reader Action Number 625.

New on the Market



Siemens Corp., Santa Clara, CA, has introduced a **codec filter** for digital telephones that offers 100 times more speakerphone switching capability than previously available. The highly-integrated codec replaces 20-40 components required for typical hands-free, speakerphone designs, making design and implementation easier, increasing reliability, reducing energy requirements, and shrinking the space needed inside the phone set by 40-50 percent. It can be used in digital telephones, voice-data terminals, voice-featured PC cards, video terminals, multimedia workstations, and cellular telephones.

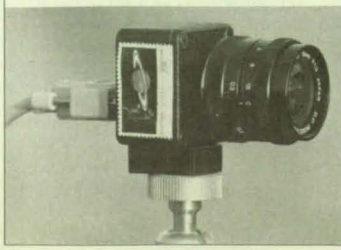
Circle Reader Action Number 616.

The Durel® 3 **electroluminescent lamp** is 50 percent thinner and lasts three times longer in severe environments than conventional EL lamps, according to the manufacturer, Rogers Corp., Rogers, CT. It protects the light source by microencapsulating the individual luminescent phosphors, eliminating the need for bulky PCTFE plastic film. A simplified lamp construction enables the Durel 3 to have near light-to-edge luminescence.

Circle Reader Action Number 615.

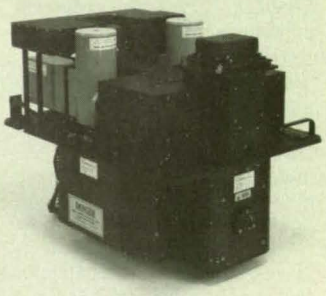
Electrim Corp., Princeton, NJ, is offering a miniature **digital electronic imager**, measuring 2" x 2" x 1.1" and weighing 4 oz. without the lens. The model EDC-1000 imager acquires clean images at rates up to 30 frames per second and provides a direct digital output of 192 x 330 x 8 bit image data. Features include easy interfacing to IBM PCs and compatibles, computer-controlled exposure time, near-linear response over a wide dynamic range, and asynchronous image capture. Applications include microscopy, machine vision, and astronomy.

Circle Reader Action Number 621.



The RGB/Videolink® 1600U **video scan converter** from RGB Spectrum, Berkeley, CA, features an optional RS-232 port for remote control from a computer. The converter transforms high-resolution computer graphics to television format in real time for recording on VCRs, teleconferencing systems, and composite monitors. The 1600U automatically synchronizes to computer displays with horizontal scan rates from 20 to 90 kHz, accepting both interlaced and non-interlaced inputs.

Circle Reader Action Number 620.



Daedalus Enterprises Inc., Ann Arbor, MI, has announced a 50-channel **infrared imaging spectrometer**. Called Wildfire, this hyperspectral imager was developed under a NASA SBIR grant to monitor the gases carried into the upper atmosphere from wildfires, study nutrient transport phenomena, and determine wildfire burning intensity. The system is suited for infrared hyperspectral studies of geological and volcanic features, and environmental applications.

Circle Reader Action Number 617.

The Rayelco™ MP series of miniature **position transducers** was designed by MagneTek, Simi Valley, CA, for applications requiring a compact and adjustable means to precisely measure a traveling object. It can be mounted in confined areas and used in aircraft drop and stress testing, automotive durability crash testing, hydraulic press and cylinder applications, and valve and robotic positioning.

Circle Reader Action Number 618.

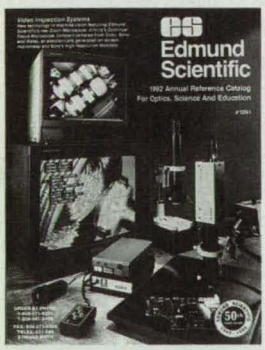
The EMT 300 **photoresist stripper** from Ardrox Inc., Campbell, CA, prevents damage to sensitive metal lines such as aluminum alloys and leaves no dry etch polymer residue. EMT 300 can strip positive photoresist baked at temperatures in excess of 150° C, as well as VIA and sidewall polymers formed after plasma etch processing. It has a relatively high flash point and contains no NMP, hazardous phenolic solution, or chlorinated hydrocarbons.

Circle Reader Action Number 619.

New Literature

Yaskawa Electric America Inc., Northbrook, IL, has released a catalog highlighting all-digital **AC servo motors**. It provides specifications, installation dimensions, and data on positioning control, electrical connections, and speed-torque curves. The servos use integrated circuits to achieve a highly-reliable design with 40 percent fewer components than other drives.
Circle Reader Action Number 611.

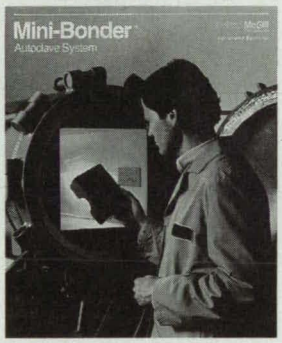
The Massachusetts Institute of Technology, Cambridge, MA, has published a catalog of **signal processing** inventions available for licensing. Featured innovations include an audio stereoscopic 3D video system, a software speech synthesizer, a fault-tolerant signal processing machine, a neural network that computes its own reliability, and a secure LCD that can only be seen by wearing special glasses. The booklet contains a list of contacts in MIT's technology licensing office.
Circle Reader Action Number 608.



A full-color catalog from Edmund Scientific Co., Barrington, NJ, presents more than 8000 **optical and industrial products**. The 196-page publication features an expanded line of technical spec optics for the OEM market, including PCX and DCX lenses, achromats, prisms, beam splitters, and corner cube reflectors. Edmund's complete line of microscopes, telescopes, magnifiers, lab equipment, and accessories is also described.
Circle Reader Action Number 614.

A 30-page **photonics** catalog from New Focus Inc., Mountain View, CA, features high-speed photodetectors, amplifiers, photoreceivers, DC power supplies, and optics. New products include a 20-GHz, 20-ps amplifier that preserves pulse fidelity, and an integrated optic modulator that simultaneously controls intensity and phase.
Circle Reader Action Number 612.

Mini-Bonder™ **autoclaves** designed for R&D and small-scale production are showcased in a new brochure from United McGill Corp., Groveport, OH. The preassembled autoclaves are available in two sizes, for workspaces 13" x 36" or 18" x 36". The standard model operates to 314 psig and 425° C, while a high-pressure/high-temperature version operates to 500 psig and 540° C. They can be used to bond composites, laminate glass and printed circuit boards, and cure rubber.
Circle Reader Action Number 613.



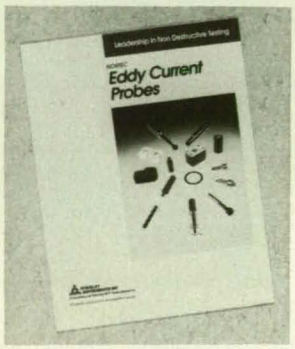
The 44-page *Instrumentation Amplifier Application Guide* from Analog Devices Inc., Norwood, MA, describes the benefits of using **instrumentation amplifiers** (in-amps) in such applications as medical instrumentation, audio, data acquisition, and high-speed signal conditioning. The illustrated guide explains basic in-amp theory and operational principles, and reviews specifications including operating conditions, gain, and nonlinearity.
Circle Reader Action Number 609.

Literature from Tosoh SMD Inc., Grove City, OH, describes the company's **thin films** for use in semiconductors, digital storage media, information displays, and other functional coatings. Tosoh SMD supplies targets in aluminum and its alloys, refractory metals, chromium, carbon, cobalt alloys, silicides, rare-earth alloys, oxides, and precious metals in virtually any configuration. The full-color brochure covers quality control, R&D, and analytical methods for achieving parts-per-trillion precision.
Circle Reader Action Number 610.

New Literature

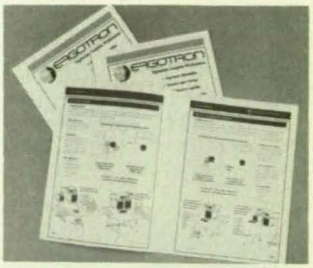
A free wall chart from Indium Corp. of America, Utica, NY, displays specifications for more than 60 **solders and fluxes**. It details solder liquidus and solidus temperatures, chemical composition, plastic range, specific gravity, electrical and thermal conductivity, and tensile and bond strength. The chart also includes a periodic table of the elements and photos of elements commonly used in solder alloys.
Circle Reader Action Number 605.

UDT Sensors, Hawthorne, CA, has announced a 52-page catalog of **photodiodes** and components. The booklet discusses the construction and application of silicon photodiodes. Among the products highlighted are PV/PC PIN photodiodes, hybrid photodetector/amplifiers, UV/blue-enhanced diodes, x-ray/UV series, detector/filter combinations, position-sensing diodes, arrays and solderable chips, and fiber optic detectors and emitters.
Circle Reader Action Number 603.



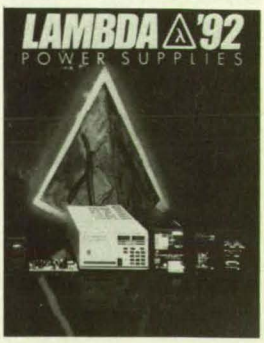
Eddy current nondestructive testing probes are highlighted in a full-color catalog from Staveley Instruments Inc., Kennewick, WA. In addition to nine types of standard probes, the catalog details scanner, detachable, and specialty probes, as well as probe kits, cables, and adaptors. It includes information on materials and test requirements, probe selection, and custom probes.
Circle Reader Action Number 606.

By the year 2001, the value of optics/electro-optics technology transferred from the military/government to industry could reach $450 million, according to a new study by Business Communication Co., Norwalk, CT. Despite cutbacks and thawing relations with the Soviet Union, optics/electro-optics will continue to have a secure role in both defense and commercial markets, predicts the study, which points to two technologies as having the greatest commercial potential—smart glass and heads-up displays.
Circle Reader Action Number 604.



Ergonomic **computer workstations** are described in a catalog from Ergotron Inc., Eagan, MN. A patented suspension system allows computer operators to hang monitors, CPUs, and other peripherals over any work surface, saving valuable desk and office space. Built with a rugged frame, the workstations feature a shelf 30" or 42" wide, a monitor caddy, gas-spring-powered radial arms capable of supporting up to 70 lbs., and a leg assembly.
Circle Reader Action Number 602.

A full-color brochure from Boeing Technology Services, Renton, WA, details the company's **testing services** for aerodynamics, materials, environmental, acoustical, structural, propulsion, and simulation applications. Laboratory facilities available to industry include transonic, supersonic, and propulsion wind tunnels, an air blast simulator, a space simulation chamber, an anechoic chamber, a high-altitude rocket engine test facility, and flight simulation domes. Also described are planned projects such as an icing tunnel and an integrated aircraft systems laboratory.
Circle Reader Action Number 601.



Lambda Electronics Inc., Melville, NY, is offering a catalog of over 1300 standard **power supplies**, power systems, and accessories. Included among 200 new products are the LZ series power supplies, featuring auto-selectable AC input, signals for AC power fail, and overvoltage protection; and the LRQ quad-output models with low-noise outputs to 35 mV pk-pk for high-grade industrial applications.
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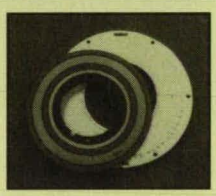

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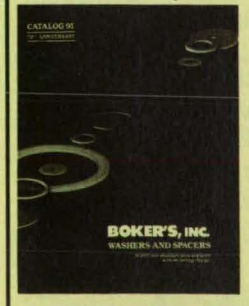

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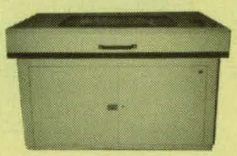

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More than 450 pages of tooling components!

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This illustrated complete line catalog includes component parts for jigs and fixtures, chuck jaws, plug gauges, threaded inserts, stainless steel tooling components, toggle clamps, SWIFTSURE power workholding devices, drill jig bushings, locking pins, and modular fixturing. Completely illustrated. **Send for your free copy.**

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Circle Reader Action No. 390

Subject Index

(continued on page 130)

NASA Tech Briefs LITERATURE SPOTLIGHT

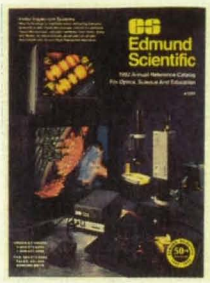
Free catalogs and literature for NASA Tech Briefs' readers. To order, circle the corresponding number on the Reader Action Request Form (page 101).

GUIDE TO ENCLOSURES

This free catalog provides an overview of the Emcor product lines: ESQ, 10 Series, Emcor I, EMI-RFI, and Compu-Desk. The catalog also provides information on Instant Emcor and custom design.

Emcor Products

Circle Reader Action No. 300



OPTICAL REFERENCE CATALOG

Edmund Scientific's free 196-page, full-color annual reference catalog features one of the largest selections of precision optics, and optical instruments, plus a complete line of components and accessories for both large volume OEM users as well as smaller research facilities and optical laboratories. It contains over 8,000 hard-to-find items including many scientific and technical products used in science, industry, and research.

Circle Reader Action No. 301

LOW-COST, PC-COMPATIBLE DATA LOGGER

Puts eight thermocouple channels on monitor, printer, or disk for $279 complete. Specifically for laboratory and industrial temperature monitoring. Avoids complex set-up or installation and is functioning within minutes. RS-232 interface powers converter and eliminates sensor wires at computer. QuickBasic®MS source code and compiled program provided. 16-channel and linear sensor options.

DCC Corp.

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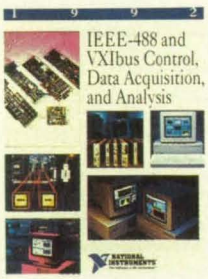
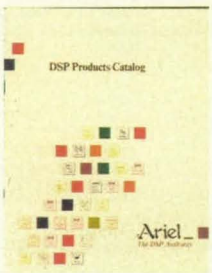


INSTRUMENT CONTROL AND DATA ACQUISITION

Free 1992 catalog of instrumentation products for PCs, workstations, and more. Features IEEE-488.2 interfaces and software, plug-in data acquisition boards, VXIbus controllers, DSP hardware and software, and signal conditioning accessories. Application software for complete acquisition, analysis, and presentation of data, including graphical interfaces. Application tutorials and training classes also detailed.

Circle Reader Action No. 303



DIGITAL SIGNAL PROCESSING

Ariel Corporation's 52-page catalog features DSP products for VMEbus,Sun SPARC - station and Macintosh. Product line includes 30 unique hardware products, plus advantaged DSP development software, flexible expansion options, and extensive third-party software support.

Ariel Corp.

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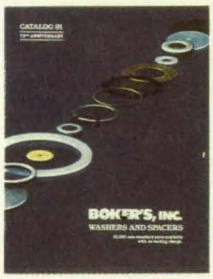


WASHERS AND SPACERS

Boker's 28-page Catalog '92 offers 10,000 nonstandard sizes with no tooling charges. Outside diameters are 0.080 to 2.631, with numerous inside diameters and thicknesses. 2,000 material variations, including plastics, create millions of possibilities.

Boker's Inc.

Circle Reader Action No. 305

O-RING-SEALED FITTINGS & VALVES

A full line of leaktight, flat-faced, o-ring-sealed fittings and valves offering the leakproof integrity of heat-sealed connections plus easy slip-in/slip-out accessibility is described in Catalog 68. The O-SEAL SYSTEM fittings and valves, in tube and pipe sizes from 1/8" to 2 1/2", are for liquid and gas service at pressures from vacuum to 6,000 psi, and temperatures from -20°F to +225°F.

CPV Mfg.

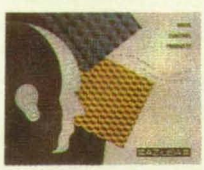
Circle Reader Action No. 306

TOOLING COMPONENTS AND CLAMPS

This 500-page catalog contains an assortment of components, including toggle clamps, modular fixturing, clamping devices, power workholding, chuck jaws, pins, knobs, drill bushings, leveling feet, and much more.

Carr Lane Mfg.

Circle Reader Action No. 307



NOISE CONTROL CATALOG

12-page catalog features noise control products & services. It includes application ideas, step-by-step guide for ordering the product & information on "guaranteed" acoustical modeling service. AZ-USA acoustical foam has a patented pyramid surface pattern that scatters, dissipates, & deflects noise. AZ-USA offers a flame-resistant version of its products, & a variety of noise control products.

AZ-USA Inc.

Circle Reader Action No. 308

HIGH-VOLTAGE DC POWER SUPPLIES

A 16-page, full-color catalog details 13 series of regulated high-voltage power supplies, 1 kV to 500 kV, 15 W to 15 kW. A quick selection guide, full specs, options, and ordering information aid the selection process.

Glassman High Voltage Inc.

Circle Reader Action No. 309

SELF-FITTING PROTECTIVE OVERSLEEVES

Bentley Harris Expando® self-fitting oversleeves provide superior abrasion and impact protection for wires, cables, and hoses. They are available in several grades and materials including PEEK/PPS rated at 200°C for low outgas specifications. Constructions include standard tubular, wraparound, and zippered which require no open end for installation, self-flaring which blossoms open at the end when cut, and end-fray resistant "Plus."

Circle Reader Action No. 310

ELECTRIC LINEAR ACTUATORS

Three series of electric rodless and standard cylinders and controls are covered in this 136-page catalog. It provides performance data, comparisons, dimensions, and accessories. Additional sections provide sizing and selection design considerations and applications.

Industrial Devices Corp.

Circle Reader Action No. 311

BRUSHLESS MOTORS AN APPLICATIONS GUIDE

Brushless Motor Applications Guide is a key design reference to maximize motor performance in specific applications. Features tables, charts, reference equations, diagrams, schematics, and conversion factors plus a glossary of motor terminology.

BEI Motion Systems Co.

Circle Reader Action No. 312

LAB/TEST FURNACES

A 36-page catalog (Bulletin 3110) describes lab/test furnaces manufactured by Applied Test Systems. Furnaces available in tubes, splits, or Boxes in configurations and sizes designed to specific customer requirements. Features include: low power consumption, fast heat-up, long element life, low shell temperature, stainless steel shell. Temperature to 3100°F.

Applied Test Systems Inc.

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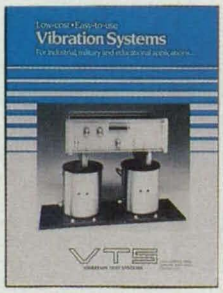

LOW-COST VIBRATION TEST SYSTEMS

Vibration systems from 25 to 600 pounds force for: research and development; products qualification; vibration stress screening; modal excitation; vibration demonstrations. Also available: multiple shaker systems; table expanders; cube fixtures; custom fixtures; slip tables.

Vibration Test Systems

Circle Reader Action No. 314

REAL-TIME NETWORK

The SCRAMNet™ network combines the real-time speed of replicated shared memory with the flexibility of a fiber optic LAN to get microsecond response from multi-vendor computers. It offers distinct advantages in critical simulations. Brochure highlights system's features.

Systran Corp.

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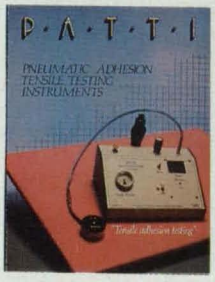
PROGRAMMABLE VIDEO GENERATORS

TEAM SYSTEMS' new six-page brochure emphasizes the advantages of Video Generators in general and the ASTRO 800 Series in particular for engineering, qualification, incoming inspection, production and marketing of monitors, projection systems, scan converters, and many other types of equipment.

Team Systems

Circle Reader Action No. 316



COATING ADHESION TESTERS

Measures the strength of paints, coatings, and adhesives. Surface can be smooth, rough, or porous. True tensile strength is measured with a pneumatic piston, up to 10,000 psi. Analog and digital models meet ASTM D4541.

Semicro Corp.

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INVESTMENT CASTINGS

PMI brochure describes our ferrous & nonferrous investment castings. Near-net-shape, internal complexity, great surface finish designed in for parts 10 pounds or less. 200 alloys, with expanded capacity for aluminum & ductile iron. Engineering & prototype services.

Precision Metalsmiths Inc.

Circle Reader Action No. 318

DIGITIZING WITH ANALYSIS

Hi-Techniques offers digitizing rates from 100 Ksps to 200 Msps in mainframes containing up to 32 channels. High-performance circuits combine the complex triggering and instant display found in digital oscilloscopes with the analysis capabilities of computers.

Hi-Techniques Inc.

Circle Reader Action No. 319

FIBER OPTIC DISPLACEMENT SENSORS

Sensors for noncontact measurement on nonconductive and conductive materials feature reflectivity compensation, high bandwidth, microinch resolution, wide temperature range, small size. Applications include dimensional measurements and motion analysis of vibrating or rotating targets. From $595.

Philtec Inc.

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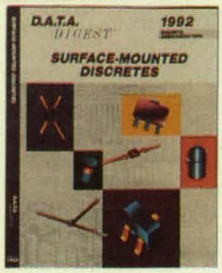

D.A.T.A. D/I/G/E/S/T/®

D.A.T.A. Business Publishing's full-line library provides information on semiconductor components for initial selection and sourcing. Pinouts, circuit connections, manufacturers' addresses and distributors and sales offices are among the sections in the DIGESTS. The libraries consist of: discrete semiconductors, integrated circuits, replacement series, surface-mounted devices, specialty references, and discontinued semiconductors.

Circle Reader Action No. 321

FIBROUS CERAMICS

Manufacturers & fabricators of high-performance, high-temperature fibrous ceramic thermal, electrical, and structural insulation products. Fiber types offered include: zirconia, alumina silica, and other refractory oxide compositions. Product forms include: bulk fiber, powders, cements, hardeners, felts, cloths, papers, boards, cylinders, ceramic composite shapes, and engineered insulation assemblies in standard and custom shapes. Heating elements and accessories are also available.

Circle Reader Action No. 322

MICRO JET 200 MINIATURE ABRASIVE BLAST SYSTEM

For the shockless machining, cutting, and etching of the hardest materials such as glass, ceramics, gem stones, carbides, etc.

Hunter Products Inc.

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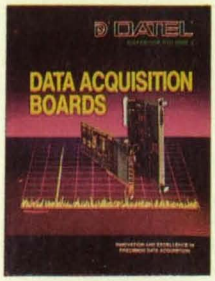


FREE DATABOOK FOR DATA ACQUISITION BOARDS

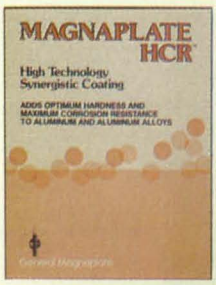
DATEL Inc. announces an all new 180-page catalog covering over 70 high-resolution, high-speed data acquisition and control boards for PC/Multibus applications. Also included are the very latest high-resolution, high-speed (up to 4 MHz), Analog I/O and DSP (PC-414 & PC-430) boards available anywhere.

Circle Reader Action No. 324

WORK STATIONS, LAB FURNITURE

Twenty-page illustrated guide covers the Teclab line of technical work stations and laboratory systems furniture. Included are versatile work stations of different lengths, combined with a choice of cabinets, shelves, parts drawers, partitions, and other accessories. Catalog has dimensions and shows typical arrangements. It also describes available work surfaces, and has a convenient color selection guide.

Circle Reader Action No. 325



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Ultra-hard MAGNAPLATE HCR® surface-enhancement treatment provides exceptionally high corrosion resistance for aluminum and aluminum alloy parts. Permanent, Magnaplate-applied "synergistic" coating creates a dry-lubricated, anti-abrasion, anti-static, anti-stick surface that withstands salt spray over 15,000 hrs. (40 times Mil Spec) and lengthens service life.

General Magnaplate Corp.

Circle Reader Action No. 326

CABINETS AND RACKS

General Devices' new 54-page Cabinets and Racks catalog features a full range of standard Vent Rak® cabinets and knock-down racks; easily modified with EMI/RFI shielding, seismic structural reinforcements, airflow provisions, access and control cutouts, and custom panel openings, widths, and depths.

General Devices Co.

Circle Reader Action No. 327

COST ESTIMATING

World's best-selling system has been updated with nine databases and full process planning capability. Provides consistent, fast estimates for job shops and Fortune 500.

Manufacturers Technologies

Circle Reader Action No. 328

PORTABLE FLUXGATE MAGNETOMETER

Literature describes a new low-cost, high-accuracy handheld fluxgate magnetometer that measures low-level magnetic fields from DC to 100 Hz for package inspection, magnetic signatures, MRI field mapping and shielding effectiveness.

Walker Scientific Inc.

Circle Reader Action No. 329

CONSTANT TEMPERATURE BATH/CIRCULATORS

NESLAB Instruments offers an entire line of constant temperature bath/circulators for life science applications such as cell culture, electrophoresis, incubation, diffusion, amino acid analysis, etc.

NESLAB Instruments Inc.

Circle Reader Action No. 330

SURFACE ANALYSIS COMPONENTS CATALOG

New Surface Analysis Components Catalog is a complete source of features, specifications, and ordering information to help you choose the components, subsystems, and ultrahigh vacuum equipment you need to economically build a customized, high performance surface analysis system.

Perkin-Elmer, Physical Electronics Div.

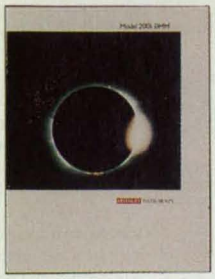
Circle Reader Action No. 331

SOLDERING, BRAZING, & WELDING WITH WATER

The SPIRFLAME free 18-page color brochure is a perfect primer to introduce the new patented technology and the laboratory and industrial applications of these water generated micro- and mini-flames to production technologies engineers.

Solder AbsorbingTech. Inc.

Circle Reader Action No. 332

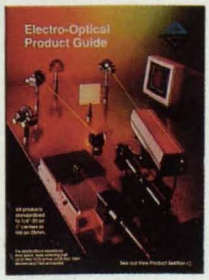


NEW HIGH PERFORMANCE DMM

Keithley offers a new high performance DMM with 18 functions and 7 1/2-digit resolution. The Model 2001 has 18ppm DCV accuracy, 0.03% ACV accuracy, and 2000 readings/sec. It also measures 1 Hz - 2 MHz ACV bandwidth, peak spikes, AC crest factor, and frequency from 1 Hz - 15 MHz.

Keithley Instruments Inc.

Circle Reader Action No. 333

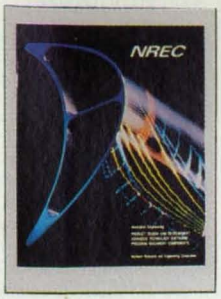


NEW POSITIONING SYSTEMS/ LASERS CATALOG

Featuring dozens of new laser, laser instrumentation and motion control products, Aerotech's guide contains hundreds of products including: Green HeNes; patented frequency stabilized one and two frequency laser systems; the world's only laser interferometer position transducer; and gives the industry's most accurate motorized positioning mounts.

Aerotech

Circle Reader Action No. 334



TURBO-MACHINERY ENGINEERING

Free brochure shows how companies that produce or operate compressors, pumps, or turbines can benefit from NREC's advanced engineering consulting expertise, specialized CAE/CAM software, and precision manufacturing services.

Northern Research and Engineering Corp.

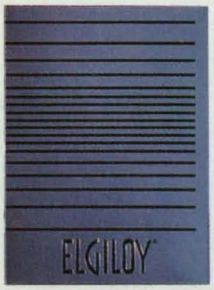
Circle Reader Action No. 335

DATA ACQUISITION AND COMMUNICATION HANDBOOK

Quatech's 1991-1992 handbook features 86 pages of the latest information on our complete line of communication, data acquisition, and waveform synthesizers. Most products are available for PC XT, AT, and MicroChannel buses. Software available.

Quatech Inc.

Circle Reader Action No. 336



HIGH-PERFORMANCE ALLOY

Elgiloy® is a high-performance nickel-cobalt alloy. This brochure describes its characteristics and properties as well as processing information. Elgiloy® is offered in strip and wire and is used in a variety of specialized applications.

Elgiloy® Limited Partnership

Circle Reader Action No. 337

HANDHELD DIGITAL SYNCHRO METER

New, pocket-sized, lightweight CSI Model DSM-4™ is ideal for troubleshooting, field-testing and on-site alignment of synchro systems. Features 0-359.9° angular readout with (+/-) 0.2° accuracy and autoranging for 11.8-, 57-, and 90-V synchros, 47 to 1200 Hz. Uses standard 9V battery; $925 each; delivery 6 wks ARO.

Control Sciences Inc.

Circle Reader Action No. 338

PROGRAMMABLE POSITION CONTROL

A complete 416-page engineer's guide with specifications, dimensions, and performance data presents brushless servos, microstepping motor systems, indexers, linear motors and absolute encoders.

Compumotor Div., Parker Hannifin Corp.

Circle Reader Action No. 339

POSITIONING SYSTEMS AND COMPONENTS

Daedal's 200-page catalog provides specifications for cross roller and ball slides; center and side drive cross roller tables; closed and open frame motorized tables; rail tables; manual and motorized rotary tables; digital micrometer stages; single- and multi-axis motion controllers; half step, microstepping and servo motor drives; and optical positioners and hardware.

Daedal Div.,Parker Hannifin Corp.

Circle Reader Action No. 340

INDUSTRIAL WORKSTATION GUIDE

Pro-Log's new 300 Series line of workstations includes four models. The top-of-the-line model is based on a 25 MHz 80486 processor running MS-DOS 5.0. Other models feature a 25 MHz 386SX/AT, a 20 MHz 80C286, or an integrated PLC (IPLC) configuration. Designed for use in all industrial environments.

Pro-Log Corp.

Circle Reader Action No. 341

MOTORS THAT SURVIVE

Empire Magnetics' 1992 catalog, "Motors That Survive," features specialized motors for hostile application environments. The 42-page catalog highlights the company's 1.8° stepper motors, brushless motors, gearboxes, brakes, and resolvers for use in harsh environments that are destructive to ordinary motors. Motor versions are rated for vacuum, radiation, high temperature, cryogenic, wet, abrasive, dusty, oily, and corrosive conditions.

Empire Magnetics Inc.

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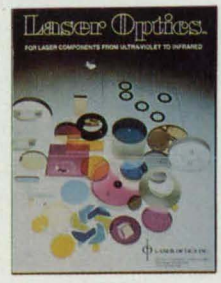

LASER COMPONENTS —UV TO IR

A 32-page catalog of optical components and coatings for ultraviolet, visible and infrared applications, including lenses, windows, prisms, beamsplitters, mirrors, and filters. Broad range of zinc selenide, germanium and silicon optics for CO_2 lasers. Specialists in optical coatings for high-power applications.

Laser Optics Inc.

Circle Reader Action No. 343

BATTERY POWERED 8-CHANNEL FIELD RECORDER

Astro-Med's portable 8-channel field recorder operable from its internal battery is described in an illustrated 10-page brochure. The lightweight unit, called the Dash 8, features extraordinary capabilities. It offers frequency response to 25 kHz; "on the fly" grid formats; AC and 11-18 VDC operation; on-demand self-calibration; and data capture and playback.

Circle Reader Action No. 344

BUILDING TOMORROW'S COMPOSITES TODAY

An overview of Brunswick's highly diversified composites capabilities plus background on its work in advanced aerospace composites, filament-winding, lamination, RTM, etc. Also includes a brief composites "primer" for those new to the field.

Brunswick Defense

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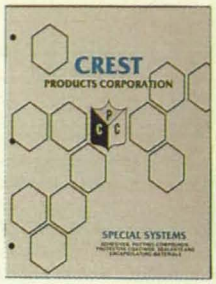

FORMULATED MATERIALS

Crest manufactures, tests, and packages adhesives, syntactic foams, sealants, potting compounds, and impregnating resins for the aircraft/aerospace, electronics, sporting goods, and a variety of other industries. Catalog offers data for materials for service at cryogenic and elevated temperatures.

Crest Products Corp.

Circle Reader Action No. 346

NEW POWER-REGULATING MODULE

UVS Plus™ is more than a line conditioner. Features include: small, lightweight design; programmable, ride-through capability. Provides regenerated, precise sinewave output and extended brownout protection. Ideal for high temperature environments. OEM modules are available.

Falcon Electric

Circle Reader Action No. 347

HIGH STABILITY MODULAR HIGH VOLTAGE POWER SUPPLIES

Spellman's MP Series HV power supplies provide a 25 ppm/°C temperature coefficient, 0.001% regulation and 0.001% peak to peak ripple. The units are available in voltages ranging from 1 kV to 15 kV at 10 Watts. The high voltage output can be controlled remotely and terminals are provided for monitoring output voltage and current.

Spellman High Voltage Electronics Corp.

Circle Reader Action No. 348

GPS TIMING FOR PC AND VMEBUS

This information folder from Bancomm describes new PCbus and VMEbus board-level Global Positioning System (GPS) Satellite Receivers. These products provide worldwide precision time (100 nanosecond) and frequency (1 part in 10E7) references inside the host computer.

Bancomm

Circle Reader Action No. 349

4kW HIGH VOLTAGE POWER SUPPLY IN A 5 1/4" HIGH CHASSIS

Extremely compact and rugged power supply in voltages from 1 kV to 60 kV at 4 kW. The SA4 is housed in a 5 1/4" H x 19" W x 22" D rack mountable chassis. The supply provides 0.1% ripple, 0.005% voltage regulation, 0.05% current regulation and low EMI and RFI due to sine wave conversion.

Spellman High Voltage Electronics Corp.

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CORROSION SERVICES

Put the LaQUE CENTER's expertise and capabilities in corrosion technology to work for you. Literature details test services for environmental and corrosion monitoring; product-equipment evaluations in corrosive environments; exposure tests in various environments; evaluating materials performance; failure analysis; and corrosion training programs.

LaQUE Center for Corrosion Technology Inc.

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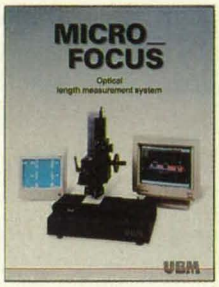

UBC-14 LASER MEASURING SYSTEM

Noncontact sensor unit with movable stage (x,y,z), computer-based controller and video monitor to show exact measuring point. Measure surface profile, roughness, flatness, etc. (practically any material) with range of 0.4" and accuracy of 0.01 µm.

UBM Corp.

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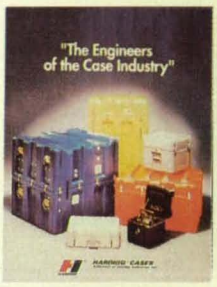

FREE CATALOG

Hardigg offers a catalog featuring their engineered shipping containers. For more than 35 years, HARDIGG has protected fragile payloads with their rugged rotationally molded polyethylene cases. Over 225 sizes to choose from, and a 19" rackmount line.

HARDIGG Cases

Circle Reader Action No. 353

SCIENTIFIC AND ENGINEERING SOFTWARE TOOLS

A demo disk and catalog is available for the Quinn-Curtis line of scientific and engineering software tools for C and Pascal programmers. Scientific charting, numerical methods, real-time graphics, measurement and control, and huge virtual array libraries are discussed in detailed data sheets.

Quinn-Curtis

Circle Reader Action No. 354

ERGONOMIC COMPUTER WORKSTATIONS

FREE catalog describes how Ergotron workstations solve space and computer integration problems in every department within your company. By ergonomically suspending monitors, CPUs, and other peripherals over the worksurface, desktop and office space is saved.

Ergotron Inc.

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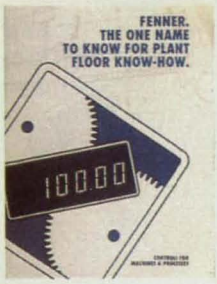

ADJUSTABLE SPEED DIGITAL MOTOR CONTROLS

Informative two-color brochure covers complete line of digital motor controls, brush type and brushless amps line, and line of electronic components. Catalog contains product photos as well as detailed specification charts and applications. Fenner Controls are perfect for unwind/rewind, coating, laminating, slitting, wrapping and labeling and embossing marking.

Fenner Industrial Controls

Circle Reader Action No. 357

PRESSURE, LOAD, ACCELERATION & LVDT'S

Sensotec's 172-page transducer handbook features complete technical data and order information on more than one hundred models of transducers. Sensotec provides complete support instrumentation and amplifiers for their full line of pressure transducers, load cells, accelerometers, and LVDTs.

Sensotec Inc.

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SYNTHESIZED FUNCTION GENERATOR

The DS 345 offers digitally synthesized waveforms to 30 micro-Hz with 1 mHz resolution, arbitrary waveform and modulated outputs. Outputs can be simple sine, triangle, ramp, or square waves; complex arbitrary signals up to 16,300 points can also be created.

Stanford Research Systems Inc.

Circle Reader Action No. 359

FREE FOAM SAMPLE MATERIALS

Included are separate specifications sheets, as well as a standard grade property comparison chart listing sizes, densities, strengths, and other properties for the usage and selection of foams. Sample pieces feature: Volara—irradiation crosslinked polyolefin, Volara S-types—second-generation cross-linked foams, Volextra—a composite that has been enhanced, and Minicel.

Voltek, Div. of Sekisui America Co.

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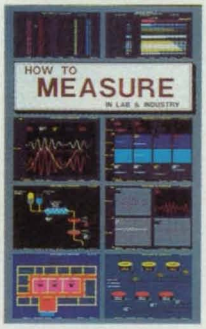

HIGH-RESOLUTION DATA ACQUISITION

FREE booklet shows many ways to automate data collection using your personal computer. It comes with a FREE Instatrend Real-Time Graphics Demo Disk.

Dianachart Inc.

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NONCONTACT DIMENSIONAL GAUGES

Brochure features Zygo's complete line of laser dimension sensors and processors including Zygo's new 1300 Series Laser Micrometer, 1600 Series Laser Process Gauge, Part-Profiler, and their newest, most advanced, full-featured processor, the 2100xp Century Series.

Zygo Corp.

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ULTRASONIC RANGING SYSTEM

Polaroid's ranging designer kits allow you to easily incorporate our highly reliable ultrasonic sensors and drive electronics into a myriad of applications. Our 4-color brochure outlines performance characteristics and schematics to give you the technical details you need for your application.

Polaroid Corporation

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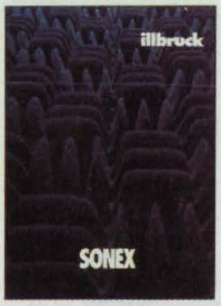

NOISE CONTROL PRODUCTS

New color brochure describes SONEX and SONEX I sound-absorbing materials with patented shapes that control noise better than standard acoustical treatments. Brochure explains basic noise control techniques and presents many forms, sizes, colors of SONEX products for industrial, office and OEM noise control. Brochure shows applications and includes information on acoustical performance.

Illbruck Inc.

Circle Reader Action No. 363

HIGH RESOLUTION FLOW VISUALIZATION

The Laserstrobe™ offers ultra short pulse width, high intensity visible light at high framing rates (32 kHz). Applications include: ballistics, wind tunnel studies, spray analysis, particle image velocimetry, flow visualization, and engine and combusion analysis.

Oxford Lasers Inc.

Circle Reader Action No. 365

TRACE OXYGEN ANALYZERS

Illinois Instruments Inc. manufactures a complete line of trace oxygen analyzers for all types of gas streams. They are available in panel mount, bench top, or as portable models. Intrinsically-safe versions as well as optional alarm setpoints and voltage and current outputs are also available.

Illinois Instruments Inc.

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Subject Index

(continued from page 123)

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International Space Year 1992

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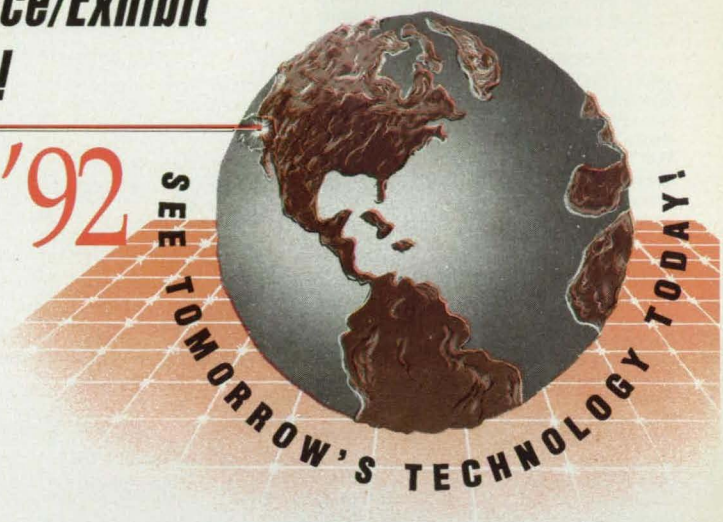

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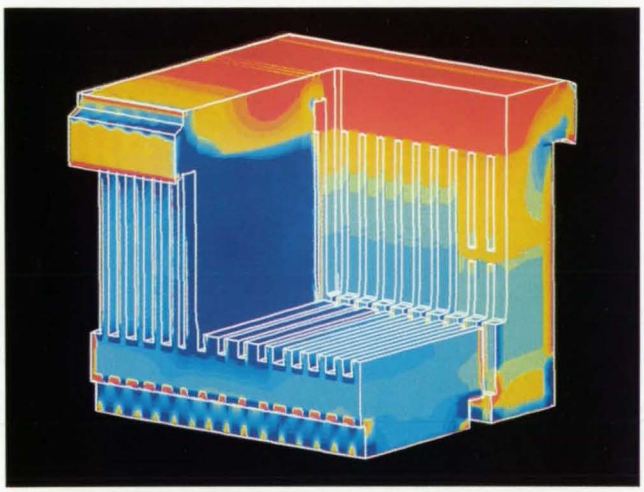

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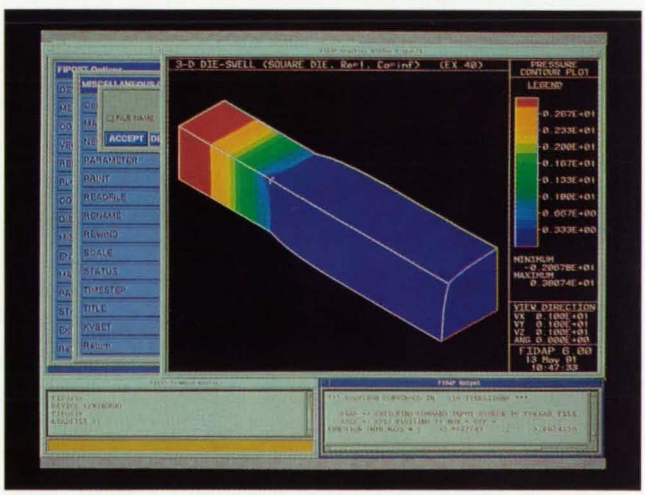

Die swell in three-dimensions/Graphical User Interface

FLUID DYNAMICS INTERNATIONAL

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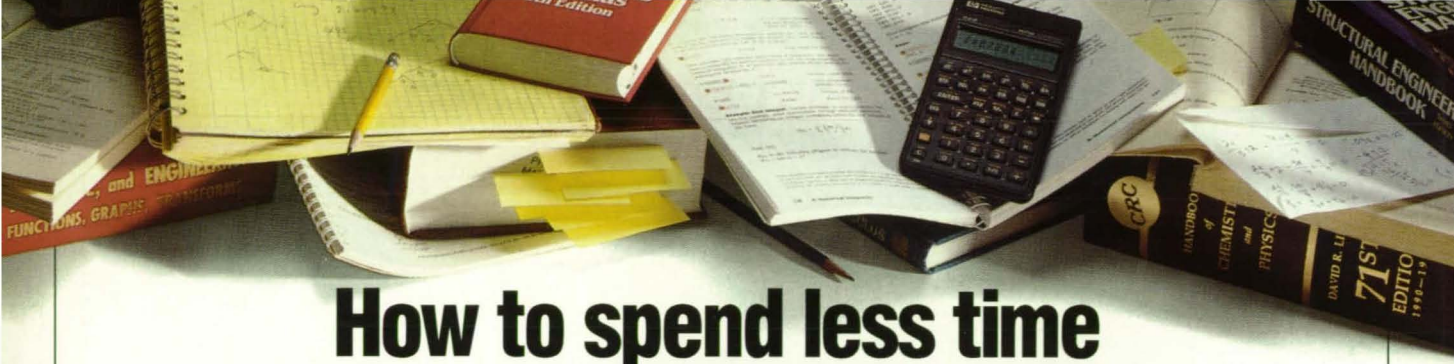

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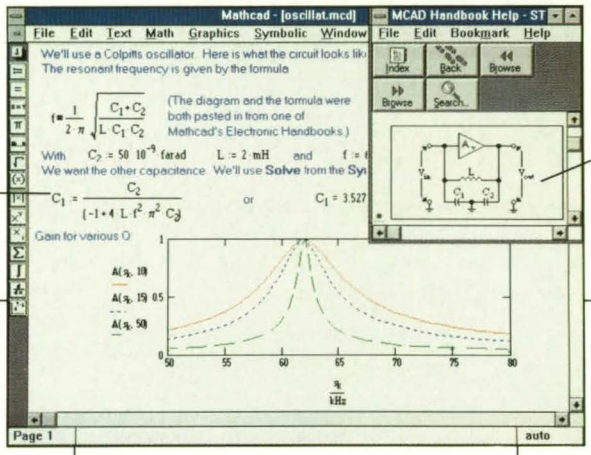

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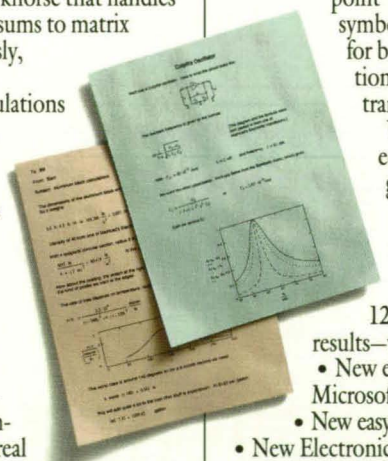

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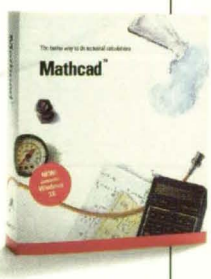

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